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(54) **COOKING OILS AND FOOD PRODUCTS**  
**COMPRISING ESTOLIDES**

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None

See application file for complete search history.

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(57) **ABSTRACT**

Cooking and frying oils comprising estolide compounds are  
described. Also described are methods of making food  
products comprising cooking or otherwise preparing at least  
one article of food with a composition comprising at least  
one estolide compound.

**23 Claims, No Drawings**

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## COOKING OILS AND FOOD PRODUCTS COMPRISING ESTOLIDES

### FIELD

The present disclosure relates to cooking and frying oils comprising estolide compounds. Also described herein are food additives comprising one or more estolide compounds.

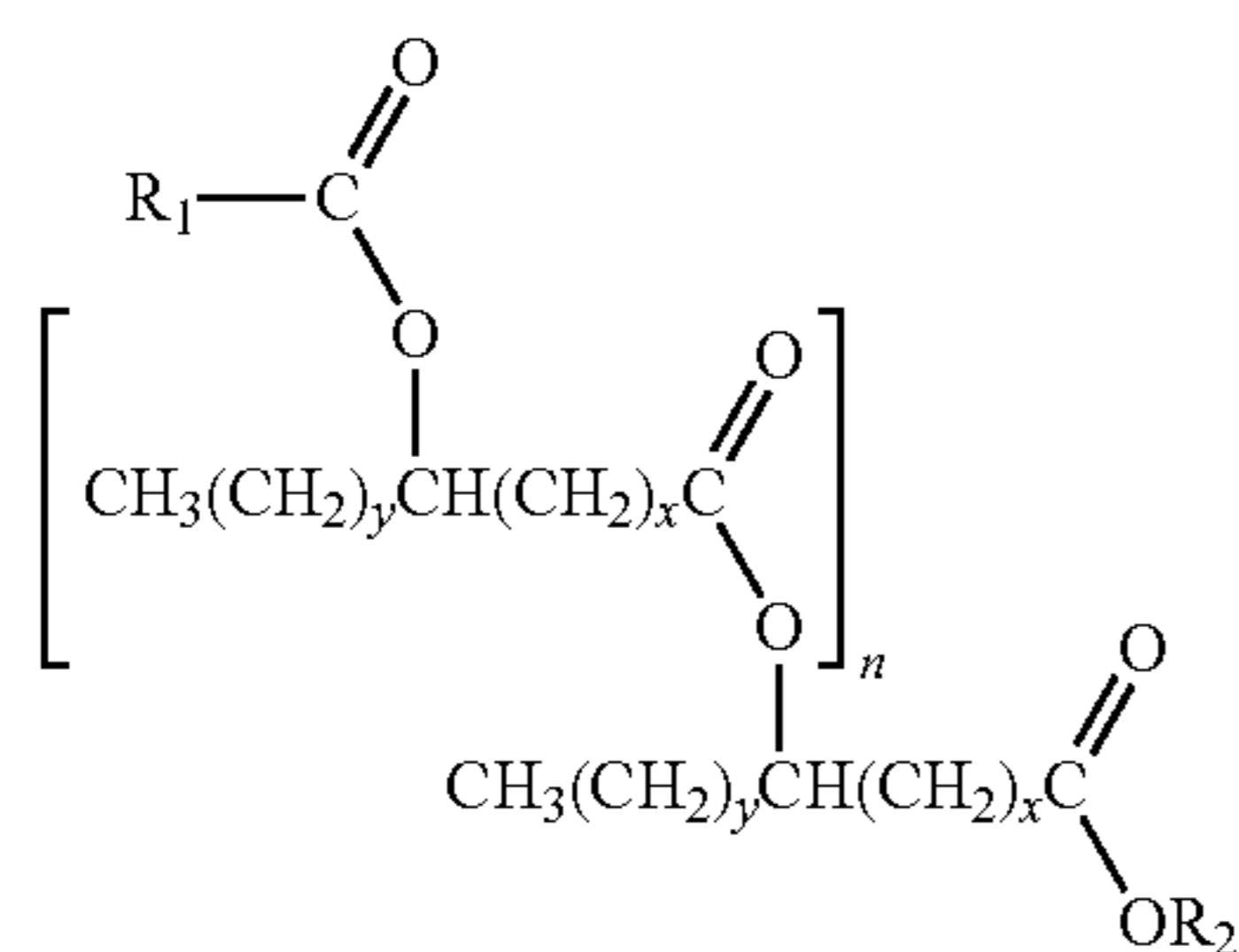
### BACKGROUND

Cooking and frying oil compositions typically comprise vegetable oil-based triglycerides. However, the relative hydrolytic instability of triglyceride molecules diminishes the fry life of such oils, resulting in the need for more frequent change intervals. Synthetic estolide compounds present a hydrolytically-stable alternative to triglycerides that may be useful in extending the fry life of cooking oil compositions. Frying/cooking food articles with estolides may also provide consumers with a healthier alternative to triglyceride-based oils.

### SUMMARY

Described herein are estolide compounds, estolide-containing compositions, and methods of making the same. In certain embodiments, such compounds and/or compositions may be useful as cooking and frying oils.

In certain embodiments, the estolides comprise at least one compound of Formula I:



wherein

x is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10;

y is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10;

n is an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12;

R<sub>1</sub> is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched; and

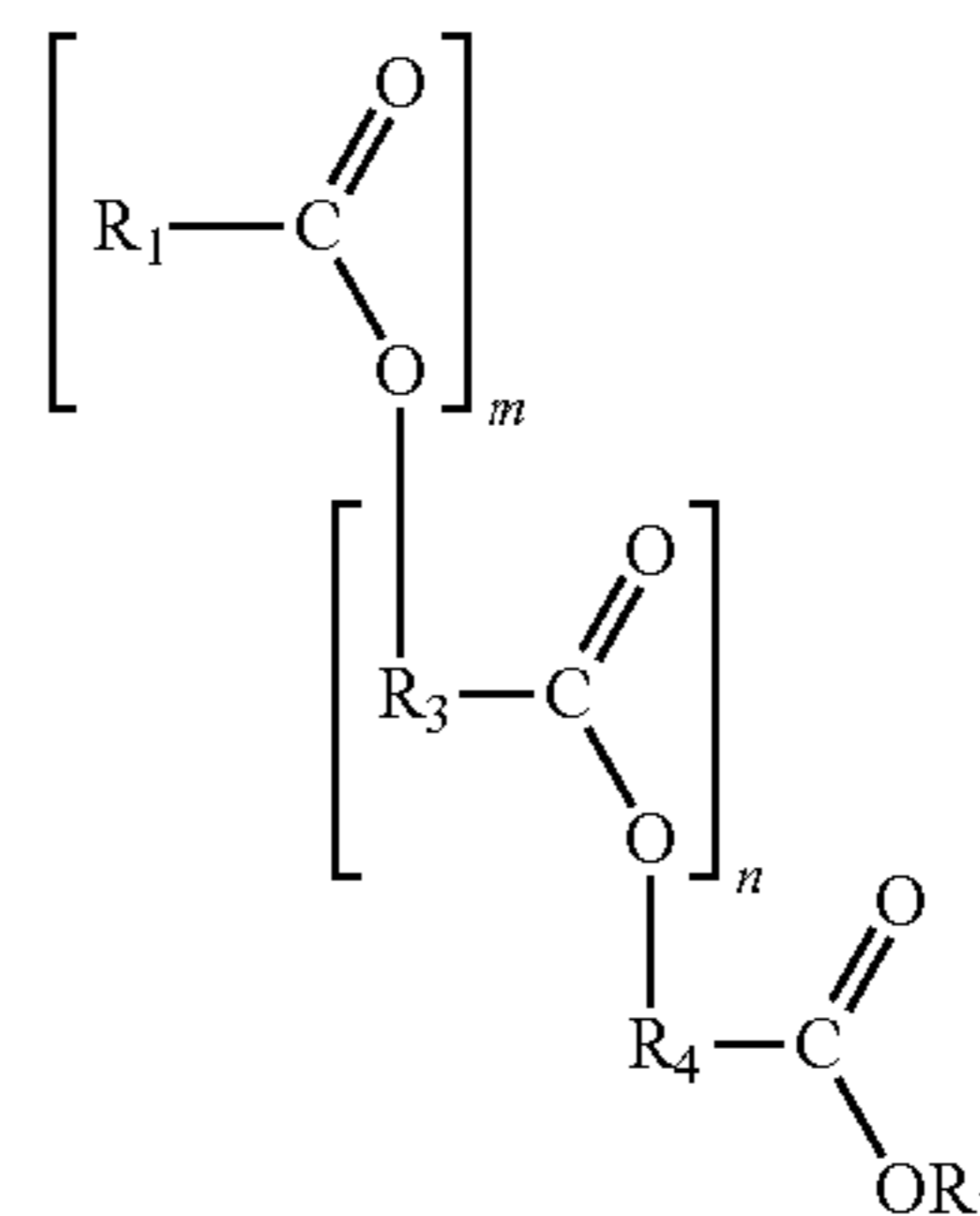
R<sub>2</sub> is selected from hydrogen and an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched;

wherein each fatty acid chain residue of said at least one compound is independently optionally substituted.

In certain embodiments, the estolides comprise at least one compound of Formula II:

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Formula II



wherein

m is an integer equal to or greater than 1;

n is an integer equal to or greater than 0;

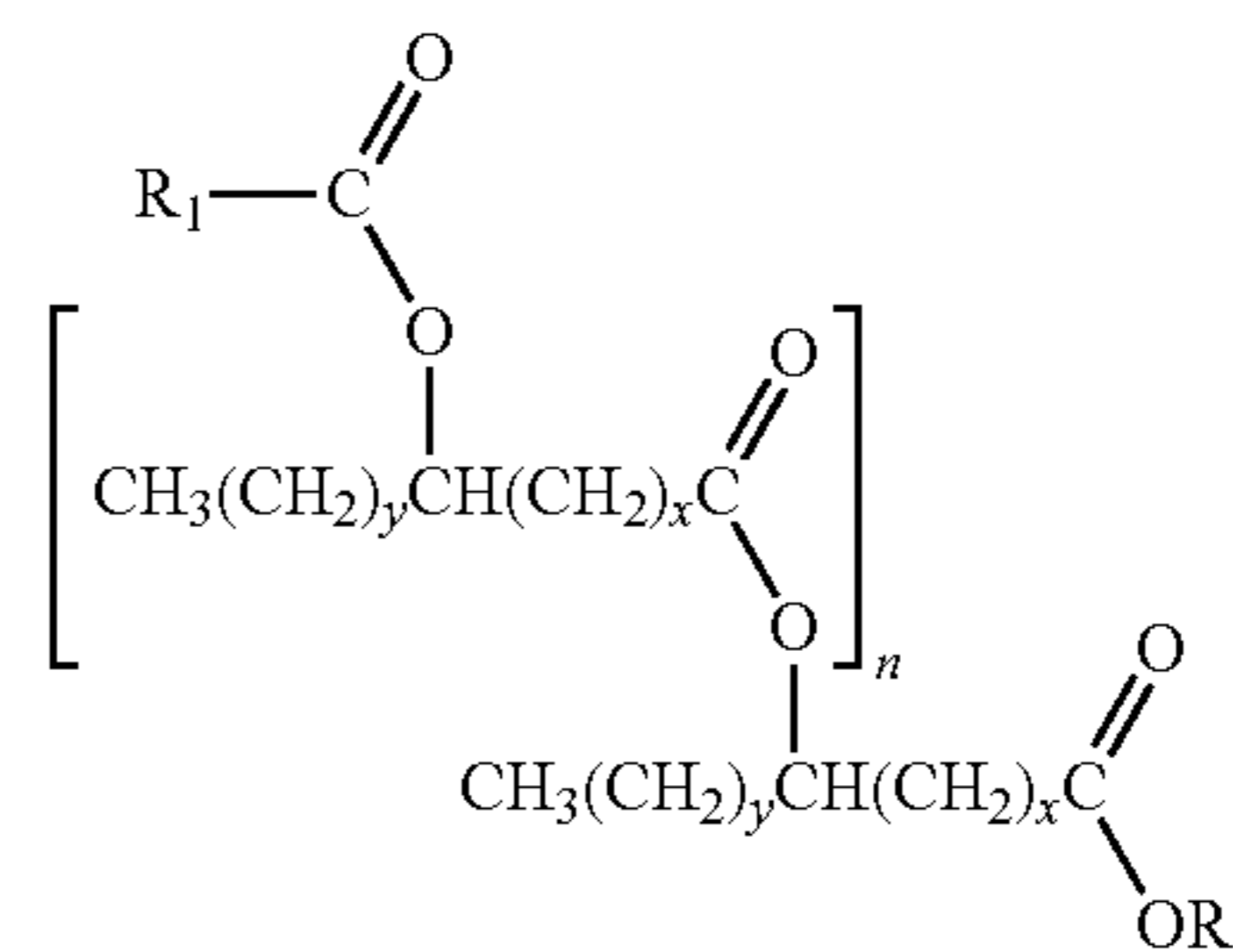
R<sub>1</sub>, independently for each occurrence, is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched;

R<sub>2</sub> is selected from hydrogen and optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched; and

R<sub>3</sub> and R<sub>4</sub>, independently for each occurrence, are selected from optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched.

In certain embodiments, the estolides comprise at least one estolide compound of Formula III:

Formula III



wherein

x is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20;

y is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20;

n is an integer equal to or greater than 0;

R<sub>1</sub> is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched; and

R<sub>2</sub> is selected from hydrogen and an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched,

wherein each fatty acid chain residue of said at least one compound is independently optionally substituted.

A food product is also described. In certain embodiments, the food product comprises at least one estolide compound. In certain embodiments, the food product is prepared by a process that includes cooking an article of food in a composition comprising at least one estolide compound.

A method of preparing a food product is also described. In certain embodiments, the method comprises cooking an article of food in a composition comprising at least one estolide compound.



## DETAILED DESCRIPTION

In addition to decreased fry life, the use of triglyceride-based fry and cooking oils presents several dietary concerns to mammalian populations, and particularly humans. Dietary fats/triglycerides are digested into free fatty acids and monoglycerides, primarily in the small intestine. Enzymes in the small intestine cleave glycerol esters at the first and third positions, resulting in free fatty acids which are absorbed into the body. Accordingly, in an effort to reduce fat consumption and absorption, there remains a need to develop low-calorie fats or fat substitutes.

One approach is to develop low-calorie fat substitutes, including substitutes for triglyceride-based cooking and frying oils. In some cases, this may be achieved by altering the structure of natural triglycerides to retain their conventional properties in foods, while eliminating their tendency toward hydrolysis and subsequent absorption during digestion. In certain embodiments, this is achieved by replacing triglycerides with one or more estolide compounds. In certain embodiments, the estolide compounds act as a fat substitute that add no fat, calories, or cholesterol to the food product.

As used in the present specification, the following words, phrases and symbols are generally intended to have the meanings as set forth below, except to the extent that the context in which they are used indicates otherwise. The following abbreviations and terms have the indicated meanings throughout:

A dash (“-”) that is not between two letters or symbols is used to indicate a point of attachment for a substituent. For example, —C(O)NH<sub>2</sub> is attached through the carbon atom.

“Alkoxy” by itself or as part of another substituent refers to a radical —OR<sup>31</sup> where R<sup>31</sup> is alkyl, cycloalkyl, cycloalkylalkyl, aryl, or arylalkyl, which can be substituted, as defined herein. In some embodiments, alkoxy groups have from 1 to 8 carbon atoms. In some embodiments, alkoxy groups have 1, 2, 3, 4, 5, 6, 7, or 8 carbon atoms. Examples of alkoxy groups include, but are not limited to, methoxy, ethoxy, propoxy, butoxy, cyclohexyloxy, and the like.

“Alkyl” by itself or as part of another substituent refers to a saturated or unsaturated, branched, or straight-chain monovalent hydrocarbon radical derived by the removal of one hydrogen atom from a single carbon atom of a parent alkane, alkene, or alkyne. Examples of alkyl groups include, but are not limited to, methyl; ethyls such as ethanyl, ethenyl, and ethynyl; propyls such as propan-1-yl, propan-2-yl, prop-1-en-1-yl, prop-1-en-2-yl, prop-2-en-1-yl (allyl), prop-1-yn-1-yl, prop-2-yn-1-yl, etc.; butyls such as butan-1-yl, butan-2-yl, 2-methyl-propan-1-yl, 2-methyl-propan-2-yl, but-1-en-1-yl, but-1-en-2-yl, 2-methyl-prop-1-en-1-yl, but-2-en-1-yl, but-2-en-2-yl, buta-1,3-dien-1-yl, buta-1,3-dien-2-yl, but-1-yn-1-yl, but-1-yn-3-yl, but-3-yn-1-yl, etc.; and the like.

Unless otherwise indicated, the term “alkyl” is specifically intended to include groups having any degree or level of saturation, i.e., groups having exclusively single carbon-carbon bonds, groups having one or more double carbon-carbon bonds, groups having one or more triple carbon-carbon bonds, and groups having mixtures of single, double, and triple carbon-carbon bonds. Where a specific level of saturation is intended, the terms “alkanyl,” “alkenyl,” and “alkynyl” are used. In certain embodiments, an alkyl group comprises from 1 to 40 carbon atoms, in certain embodiments, from 1 to 22 or 1 to 18 carbon atoms, in certain embodiments, from 1 to 16 or 1 to 8 carbon atoms, and in certain embodiments from 1 to 6 or 1 to 3 carbon atoms. In

certain embodiments, an alkyl group comprises from 8 to 22 carbon atoms, in certain embodiments, from 8 to 18 or 8 to 16. In some embodiments, the alkyl group comprises from 3 to 20 or 7 to 17 carbons. In some embodiments, the alkyl group comprises 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, or 22 carbon atoms.

“Aryl” by itself or as part of another substituent refers to a monovalent aromatic hydrocarbon radical derived by the removal of one hydrogen atom from a single carbon atom of a parent aromatic ring system. Aryl encompasses 5- and 6-membered carbocyclic aromatic rings, for example, benzene; bicyclic ring systems wherein at least one ring is carbocyclic and aromatic, for example, naphthalene, indane, and tetralin; and tricyclic ring systems wherein at least one ring is carbocyclic and aromatic, for example, fluorene. Aryl encompasses multiple ring systems having at least one carbocyclic aromatic ring fused to at least one carbocyclic aromatic ring, cycloalkyl ring, or heterocycloalkyl ring. For example, aryl includes 5- and 6-membered carbocyclic aromatic rings fused to a 5- to 7-membered non-aromatic heterocycloalkyl ring containing one or more heteroatoms chosen from N, O, and S. For such fused, bicyclic ring systems wherein only one of the rings is a carbocyclic aromatic ring, the point of attachment may be at the carbocyclic aromatic ring or the heterocycloalkyl ring. Examples of aryl groups include, but are not limited to, groups derived from aceanthrylene, acenaphthylene, acephenanthrylene, anthracene, azulene, benzene, chrysene, coronene, fluoranthene, fluorene, hexacene, hexaphene, hexylene, as-indacene, s-indacene, indane, indene, naphthalene, octacene, octaphene, octalene, ovalene, penta-2,4-diene, pentacene, pentalene, pentaphene, perylene, phenalene, phenanthrene, picene, pleiadene, pyrene, pyranthrene, rubicene, triphenylene, trinaphthalene, and the like. In certain embodiments, an aryl group can comprise from 5 to 20 carbon atoms, and in certain embodiments, from 5 to 12 carbon atoms. In certain embodiments, an aryl group can comprise 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 carbon atoms. Aryl, however, does not encompass or overlap in any way with heteroaryl, separately defined herein. Hence, a multiple ring system in which one or more carbocyclic aromatic rings is fused to a heterocycloalkyl aromatic ring, is heteroaryl, not aryl, as defined herein.

“Arylalkyl” by itself or as part of another substituent refers to an acyclic alkyl radical in which one of the hydrogen atoms bonded to a carbon atom, typically a terminal or sp<sup>3</sup> carbon atom, is replaced with an aryl group. Examples of arylalkyl groups include, but are not limited to, benzyl, 2-phenylethan-1-yl, 2-phenylethen-1-yl, naphthylmethyl, 2-naphthylethan-1-yl, 2-naphthylethen-1-yl, naphthobenzyl, 2-naphthophenylethan-1-yl, and the like. Where specific alkyl moieties are intended, the nomenclature arylalkanyl, arylalkenyl, or arylalkynyl is used. In certain embodiments, an arylalkyl group is C<sub>7-30</sub> arylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the arylalkyl group is C<sub>1-10</sub> and the aryl moiety is C<sub>6-20</sub>, and in certain embodiments, an arylalkyl group is C<sub>7-20</sub> arylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the arylalkyl group is C<sub>1-8</sub> and the aryl moiety is C<sub>6-12</sub>.

Estolide “base oil” and “base stock”, unless otherwise indicated, refer to any composition comprising one or more estolide compounds. It should be understood that an estolide “base oil” or “base stock” is not limited to compositions for a particular use, and may generally refer to compositions comprising one or more estolides, including mixtures of estolides. Estolide base oils and base stocks can also include compounds other than estolides.



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The term “catalyst” refers to single chemical species; physical combinations of chemical species, such as mixtures, alloys, and the like; and combinations of one or more catalyst within the same region or location of a reactor or reaction vessel. Examples of catalyst include, e.g., Lewis acids, Bronsted acids, and Bismuth catalysts, wherein Lewis acids, Bronsted acids, and Bismuth catalysts may be single chemical species; physical combinations of chemical species, such as mixtures, alloys, and the like; and combinations of one or more catalyst within the same region or location of a reactor or reaction vessel.

“Compounds” refers to compounds encompassed by structural Formula I, II, and III herein and includes any specific compounds within the formula whose structure is disclosed herein. Compounds may be identified either by their chemical structure and/or chemical name. When the chemical structure and chemical name conflict, the chemical structure is determinative of the identity of the compound. The compounds described herein may contain one or more chiral centers and/or double bonds and therefore may exist as stereoisomers such as double-bond isomers (i.e., geometric isomers), enantiomers, or diastereomers. Accordingly, any chemical structures within the scope of the specification depicted, in whole or in part, with a relative configuration encompass all possible enantiomers and stereoisomers of the illustrated compounds including the stereoisomerically pure form (e.g., geometrically pure, enantiomerically pure, or diastereomerically pure) and enantiomeric and stereoisomeric mixtures. Enantiomeric and stereoisomeric mixtures may be resolved into their component enantiomers or stereoisomers using separation techniques or chiral synthesis techniques well known to the skilled artisan.

For the purposes of the present disclosure, “chiral compounds” are compounds having at least one center of chirality (i.e. at least one asymmetric atom, in particular at least one asymmetric C atom), having an axis of chirality, a plane of chirality or a screw structure. “Achiral compounds” are compounds which are not chiral.

Compounds of Formula I, II, and III include, but are not limited to, optical isomers of compounds of Formula I, II, and III, racemates thereof, and other mixtures thereof. In such embodiments, the single enantiomers or diastereomers, i.e., optically active forms, can be obtained by asymmetric synthesis or by resolution of the racemates. Resolution of the racemates may be accomplished by, for example, chromatography, using, for example a chiral high-pressure liquid chromatography (HPLC) column. However, unless otherwise stated, it should be assumed that Formula I, II, and III cover all asymmetric variants of the compounds described herein, including isomers, racemates, enantiomers, diastereomers, and other mixtures thereof. In addition, compounds of Formula I, II and III include Z- and E-forms (e.g., cis- and trans-forms) of compounds with double bonds. The compounds of Formula I, II, and III may also exist in several tautomeric forms including the enol form, the keto form, and mixtures thereof. Accordingly, the chemical structures depicted herein encompass all possible tautomeric forms of the illustrated compounds.

“Cycloalkyl” by itself or as part of another substituent refers to a saturated or unsaturated cyclic alkyl radical. Where a specific level of saturation is intended, the nomenclature “cycloalkanyl” or “cycloalkenyl” is used. Examples of cycloalkyl groups include, but are not limited to, groups derived from cyclopropane, cyclobutane, cyclopentane, cyclohexane, and the like. In certain embodiments, a cycloalkyl group is C<sub>3-15</sub> cycloalkyl, and in certain embodiments, C<sub>3-12</sub> cycloalkyl or C<sub>5-12</sub> cycloalkyl. In certain

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embodiments, a cycloalkyl group is a C<sub>5</sub>, C<sub>6</sub>, C<sub>7</sub>, C<sub>8</sub>, C<sub>9</sub>, C<sub>10</sub>, C<sub>11</sub>, C<sub>12</sub>, C<sub>13</sub>, C<sub>14</sub>, or C<sub>15</sub> cycloalkyl.

“Cycloalkylalkyl” by itself or as part of another substituent refers to an acyclic alkyl radical in which one of the hydrogen atoms bonded to a carbon atom, typically a terminal or sp<sup>3</sup> carbon atom, is replaced with a cycloalkyl group. Where specific alkyl moieties are intended, the nomenclature cycloalkylalkanyl, cycloalkylalkenyl, or cycloalkylalkynyl is used. In certain embodiments, a cycloalkylalkyl group is C<sub>7-30</sub> cycloalkylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the cycloalkylalkyl group is C<sub>1-10</sub> and the cycloalkyl moiety is C<sub>6-20</sub>, and in certain embodiments, a cycloalkylalkyl group is C<sub>7-20</sub> cycloalkylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the cycloalkylalkyl group is C<sub>1-8</sub> and the cycloalkyl moiety is C<sub>4-20</sub> or C<sub>6-12</sub>.

“Halogen” refers to a fluoro, chloro, bromo, or iodo group.

“Heteroaryl” by itself or as part of another substituent refers to a monovalent heteroaromatic radical derived by the removal of one hydrogen atom from a single atom of a parent heteroaromatic ring system. Heteroaryl encompasses multiple ring systems having at least one aromatic ring fused to at least one other ring, which can be aromatic or non-aromatic in which at least one ring atom is a heteroatom. Heteroaryl encompasses 5- to 12-membered aromatic, such as 5- to 7-membered, monocyclic rings containing one or more, for example, from 1 to 4, or in certain embodiments, from 1 to 3, heteroatoms chosen from N, O, and S, with the remaining ring atoms being carbon; and bicyclic heterocycloalkyl rings containing one or more, for example, from 1 to 4, or in certain embodiments, from 1 to 3, heteroatoms chosen from N, O, and S, with the remaining ring atoms being carbon and wherein at least one heteroatom is present in an aromatic ring. For example, heteroaryl includes a 5- to 7-membered heterocycloalkyl, aromatic ring fused to a 5- to 7-membered cycloalkyl ring. For such fused, bicyclic heteroaryl ring systems wherein only one of the rings contains one or more heteroatoms, the point of attachment may be at the heteroaromatic ring or the cycloalkyl ring. In certain embodiments, when the total number of N, S, and O atoms in the heteroaryl group exceeds one, the heteroatoms are not adjacent to one another. In certain embodiments, the total number of N, S, and O atoms in the heteroaryl group is not more than two. In certain embodiments, the total number of N, S, and O atoms in the aromatic heterocycle is not more than one. Heteroaryl does not encompass or overlap with aryl as defined herein.

Examples of heteroaryl groups include, but are not limited to, groups derived from acridine, arsinole, carbazole, β-carboline, chromane, chromene, cinnoline, furan, imidazole, indazole, indole, indoline, indolizine, isobenzofuran, isochromene, isoindole, isoindoline, isoquinoline, isothiazole, isoxazole, naphthyridine, oxadiazole, oxazole, perimidine, phenanthridine, phenanthroline, phenazine, phthalazine, pteridine, purine, pyran, pyrazine, pyrazole, pyridazine, pyridine, pyrimidine, pyrrole, pyrrolizine, quinazoline, quinoline, quinolizine, quinoxaline, tetrazole, thiadiazole, thiazole, thiophene, triazole, xanthene, and the like. In certain embodiments, a heteroaryl group is from 5- to 20-membered heteroaryl, and in certain embodiments from 5- to 12-membered heteroaryl or from 5- to 10-membered heteroaryl. In certain embodiments, a heteroaryl group is a 5-, 6-, 7-, 8-, 9-, 10-, 11-, 12-, 13-, 14-, 15-, 16-, 17-, 18-, 19-, or 20-membered heteroaryl. In certain embodiments heteroaryl groups



are those derived from thiophene, pyrrole, benzothiophene, benzofuran, indole, pyridine, quinoline, imidazole, oxazole, and pyrazine.

“Heteroarylalkyl” by itself or as part of another substituent refers to an acyclic alkyl radical in which one of the hydrogen atoms bonded to a carbon atom, typically a terminal or  $sp^3$  carbon atom, is replaced with a heteroaryl group. Where specific alkyl moieties are intended, the nomenclature heteroarylalkanyl, heteroarylalkenyl, or heteroarylalkynyl is used. In certain embodiments, a heteroarylalkyl group is a 6- to 30-membered heteroarylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the heteroarylalkyl is 1- to 10-membered and the heteroaryl moiety is a 5- to 20-membered heteroaryl, and in certain embodiments, 6- to 20-membered heteroarylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the heteroarylalkyl is 1- to 8-membered and the heteroaryl moiety is a 5- to 12-membered heteroaryl.

“Heterocycloalkyl” by itself or as part of another substituent refers to a partially saturated or unsaturated cyclic alkyl radical in which one or more carbon atoms (and any associated hydrogen atoms) are independently replaced with the same or different heteroatom. Examples of heteroatoms to replace the carbon atom(s) include, but are not limited to, N, P, O, S, Si, etc. Where a specific level of saturation is intended, the nomenclature “heterocycloalkanyl” or “heterocycloalkenyl” is used. Examples of heterocycloalkyl groups include, but are not limited to, groups derived from epoxides, azirines, thiiranes, imidazolidine, morpholine, piperazine, piperidine, pyrazolidine, pyrrolidine, quinuclidine, and the like.

“Heterocycloalkylalkyl” by itself or as part of another substituent refers to an acyclic alkyl radical in which one of the hydrogen atoms bonded to a carbon atom, typically a terminal or  $sp^3$  carbon atom, is replaced with a heterocycloalkyl group. Where specific alkyl moieties are intended, the nomenclature heterocycloalkylalkanyl, heterocycloalkylalkenyl, or heterocycloalkylalkynyl is used. In certain embodiments, a heterocycloalkylalkyl group is a 6- to 30-membered heterocycloalkylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the heterocycloalkylalkyl is 1- to 10-membered and the heterocycloalkyl moiety is a 5- to 20-membered heterocycloalkyl, and in certain embodiments, 6- to 20-membered heterocycloalkylalkyl, e.g., the alkanyl, alkenyl, or alkynyl moiety of the heterocycloalkylalkyl is 1- to 8-membered and the heterocycloalkyl moiety is a 5- to 12-membered heterocycloalkyl.

“Mixture” refers to a collection of molecules or chemical substances. Each component in a mixture can be independently varied. A mixture may contain, or consist essentially of, two or more substances intermingled with or without a constant percentage composition, wherein each component may or may not retain its essential original properties, and where molecular phase mixing may or may not occur. In mixtures, the components making up the mixture may or may not remain distinguishable from each other by virtue of their chemical structure.

“Parent aromatic ring system” refers to an unsaturated cyclic or polycyclic ring system having a conjugated  $\pi$  (pi) electron system. Included within the definition of “parent aromatic ring system” are fused ring systems in which one or more of the rings are aromatic and one or more of the rings are saturated or unsaturated, such as, for example, fluorene, indane, indene, phenalene, etc. Examples of parent aromatic ring systems include, but are not limited to, acenaphthylene, acenaphthylene, acephenanthrylene, anthracene, azulene, benzene, chrysene, coronene, fluoranthene, fluorene, hexacene, hexaphene, hexylene, as-indacene, s-in-

dacene, indane, indene, naphthalene, octacene, octaphene, octalene, ovalene, penta-2,4-diene, pentacene, pentalene, pentaphene, perylene, phenalene, phenanthrene, picene, pleiadene, pyrene, pyranthrene, rubicene, triphenylene, trinaphthalene, and the like.

“Parent heteroaromatic ring system” refers to a parent aromatic ring system in which one or more carbon atoms (and any associated hydrogen atoms) are independently replaced with the same or different heteroatom. Examples of heteroatoms to replace the carbon atoms include, but are not limited to, N, P, O, S, Si, etc. Specifically included within the definition of “parent heteroaromatic ring systems” are fused ring systems in which one or more of the rings are aromatic and one or more of the rings are saturated or unsaturated, such as, for example, arsindole, benzodioxan, benzofuran, chromane, chromene, indole, indoline, xanthene, etc. Examples of parent heteroaromatic ring systems include, but are not limited to, arsindole, carbazole,  $\beta$ -carboline, chromane, chromene, cinnoline, furan, imidazole, indazole, indole, indoline, indolizine, isobenzofuran, isochromene, isoindole, isoindoline, isoquinoline, isothiazole, isoxazole, naphthyridine, oxadiazole, oxazole, perimidine, phenanthridine, phenanthroline, phenazine, phthalazine, pteridine, purine, pyran, pyrazine, pyrazole, pyridazine, pyridine, pyrimidine, pyrrole, pyrrolizine, quinazoline, quinoline, quinolizine, quinoxaline, tetrazole, thiadiazole, thiazole, thiophene, triazole, xanthene, and the like.

“Substituted” refers to a group in which one or more hydrogen atoms are independently replaced with the same or different substituent(s). Examples of substituents include, but are not limited to,  $-R^{64}$ ,  $-R^{60}$ ,  $-O^-$ ,  $-OH$ ,  $=O$ ,  $-OR^{60}$ ,  $-SR^{60}$ ,  $-S^-$ ,  $=S$ ,  $-NR^{60}R^{61}$ ,  $=NR^{60}$ ,  $-CN$ ,  $-CF_3$ ,  $-OCN$ ,  $-SCN$ ,  $-NO$ ,  $-NO_2$ ,  $=N_2$ ,  $-N_3$ ,  $-S(O)_2O^-$ ,  $-S(O)_2OH$ ,  $-S(O)_2R^{60}$ ,  $-OS(O_2)O^-$ ,  $-OS(O)_2R^{60}$ ,  $-P(O)(O^-)_2$ ,  $-P(O)(OR^{60})(O^-)$ ,  $-OP(O)(OR^{60})(OR^{61})$ ,  $-C(O)R^{60}$ ,  $-C(S)R^{60}$ ,  $-C(O)OR^{60}$ ,  $-C(O)NR^{60}R^{61}$ ,  $-C(O)O^-$ ,  $-C(S)OR^{60}$ ,  $-NR^{62}C(O)NR^{60}R^{61}$ ,  $-NR^{62}C(S)NR^{60}R^{61}$ ,  $-NR^{62}C(NR^{63})NR^{60}R^{61}$ ,  $-C(NR^{62})NR^{60}R^{61}$ ,  $-S(O)_2$ ,  $NR^{60}R^{61}$ ,  $-NR^{63}S(O)_2R^{60}$ ,  $-NR^{63}C(O)R^{60}$ , and  $-S(O)R^{60}$ ;

wherein each  $-R^{64}$  is independently a halogen; each  $R^{60}$  and  $R^{61}$  are independently alkyl, substituted alkyl, alkoxy, substituted alkoxy, cycloalkyl, substituted cycloalkyl, heterocycloalkyl, substituted heterocycloalkyl, aryl, substituted aryl, heteroaryl, substituted heteroaryl, arylalkyl, substituted arylalkyl, heteroarylalkyl, or substituted heteroarylalkyl, or  $R^{60}$  and  $R^{61}$  together with the nitrogen atom to which they are bonded form a heterocycloalkyl, substituted heterocycloalkyl, heteroaryl, or substituted heteroaryl ring, and  $R^{62}$  and  $R^{63}$  are independently alkyl, substituted alkyl, aryl, substituted aryl, arylalkyl, substituted arylalkyl, cycloalkyl, substituted cycloalkyl, heterocycloalkyl, substituted heterocycloalkyl, heteroaryl, substituted heteroaryl, heteroarylalkyl, or substituted heteroarylalkyl, or  $R^{62}$  and  $R^{63}$  together with the atom to which they are bonded form one or more heterocycloalkyl, substituted heterocycloalkyl, heteroaryl, or substituted heteroaryl rings;

wherein the “substituted” substituents, as defined above for  $R^{60}$ ,  $R^{61}$ ,  $R^{62}$ , and  $R^{63}$ , are substituted with one or more, such as one, two, or three, groups independently selected from alkyl, -alkyl-OH, -O-haloalkyl, -alkyl-NH<sub>2</sub>, alkoxy, cycloalkyl, cycloalkylalkyl, heterocycloalkyl, heterocycloalkylalkyl, aryl, heteroaryl, arylalkyl, heteroarylalkyl,  $-O^-$ ,  $-OH$ ,  $=O$ ,  $-O$ -alkyl,  $-O$ -aryl,  $-O$ -heteroarylalkyl,  $-O$ -cycloalkyl,  $-O$ -heterocycloalkyl,  $-SH$ ,  $-S^-$ ,  $=S$ ,  $-S$ -alkyl,  $-S$ -aryl,  $-S$ -heteroarylalkyl,  $-S$ -cycloalkyl,  $-S$ -heterocycloalkyl,  $-NH_2$ ,  $=NH$ ,  $-CN$ ,



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—CF<sub>3</sub>, —OCN, —SCN, —NO, —NO<sub>2</sub>, =N<sub>2</sub>, —N<sub>3</sub>,  
 —S(O)<sub>2</sub>O<sup>-</sup>, —S(O)<sub>2</sub>, —S(O)<sub>2</sub>OH, —OS(O<sub>2</sub>)O<sup>-</sup>, —SO<sub>2</sub>  
 (alkyl), —SO<sub>2</sub>(phenyl), —SO<sub>2</sub>(haloalkyl), —SO<sub>2</sub>NH<sub>2</sub>,  
 —SO<sub>2</sub>NH(alkyl), —SO<sub>2</sub>NH(phenyl), —P(O)(O<sup>-</sup>)<sub>2</sub>, —P(O)  
 (O-alkyl)(O<sup>-</sup>), —OP(O)(O-alkyl)(O-alkyl), —CO<sub>2</sub>H,  
 —C(O)O(alkyl), —CON(alkyl)(alkyl), —CONH(alkyl),  
 —CONH<sub>2</sub>, —C(O)(alkyl), —C(O)(phenyl), —C(O)(ha-  
 loalkyl), —OC(O)(alkyl), —N(alkyl)(alkyl), —NH(alkyl),  
 —N(alkyl)(alkylphenyl), —NH(alkylphenyl), —NHC(O)  
 (alkyl), —NHC(O)(phenyl), —N(alkyl)C(O)(alkyl), and  
 —N(alkyl)C(O)(phenyl).

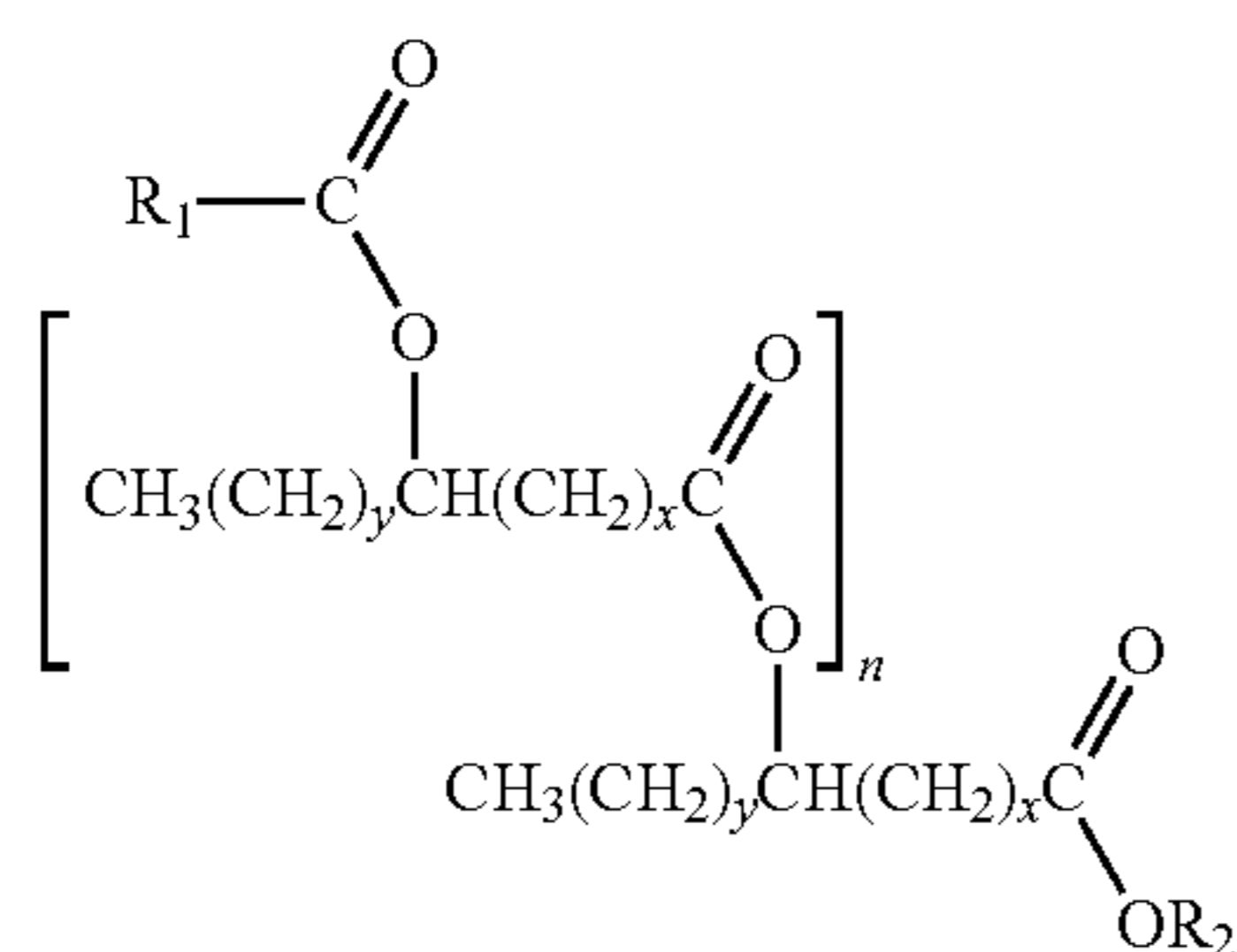
As used in this specification and the appended claims, the articles “a,” “an,” and “the” include plural referents unless expressly and unequivocally limited to one referent.

The term “fatty acid” refers to any natural or synthetic carboxylic acid comprising an alkyl chain that may be saturated, monounsaturated, or polyunsaturated, and may have straight or branched chains. The fatty acid may also be substituted. “Fatty acid,” as used herein, includes short chain alkyl carboxylic acid including, for example, acetic acid, propionic acid, etc.

All numerical ranges herein include all numerical values and ranges of all numerical values within the recited range of numerical values.

The present disclosure relates to estolide compounds, compositions and methods of making the same. In certain embodiments, the present disclosure also relates to estolide compounds, compositions comprising estolide compounds, the synthesis of such compounds, and the formulation of such compositions. In certain embodiments, the present disclosure relates to cooking oils, frying oils, and food additives comprising one or more estolide compounds. In certain embodiments are described methods of preparing food products, comprising cooking at least one article of food in a composition comprising at least one estolide compound.

In certain embodiments, the estolides comprise at least one compound of Formula I:



Formula I

wherein

x is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10;

y is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10;

n is an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12;

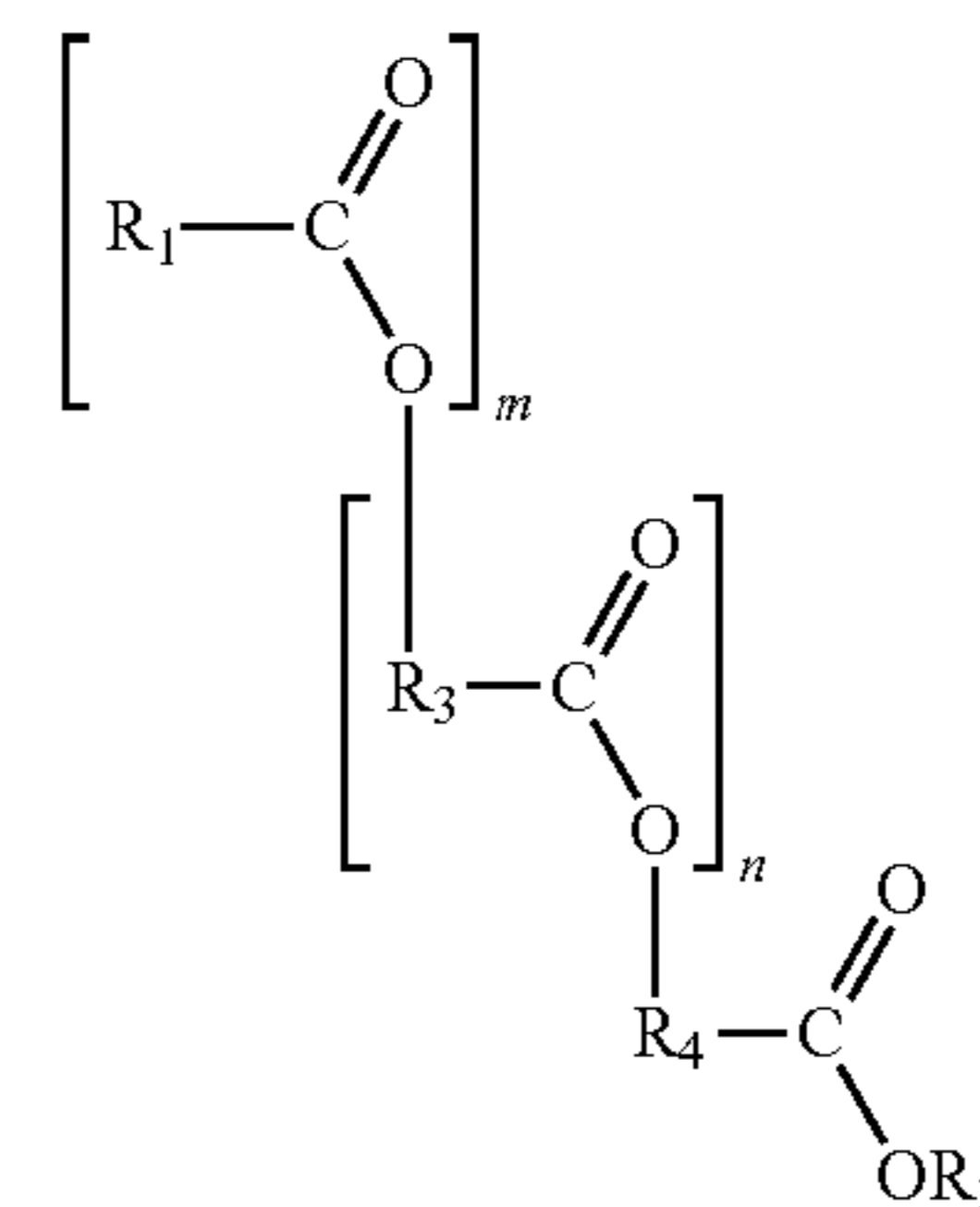
R<sub>1</sub> is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched; and

R<sub>2</sub> is selected from hydrogen and an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched;

wherein each fatty acid chain residue of said at least one compound is independently optionally substituted.

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In certain embodiments, the estolides comprise at least one compound of Formula II:



Formula II

wherein

m is an integer equal to or greater than 1;

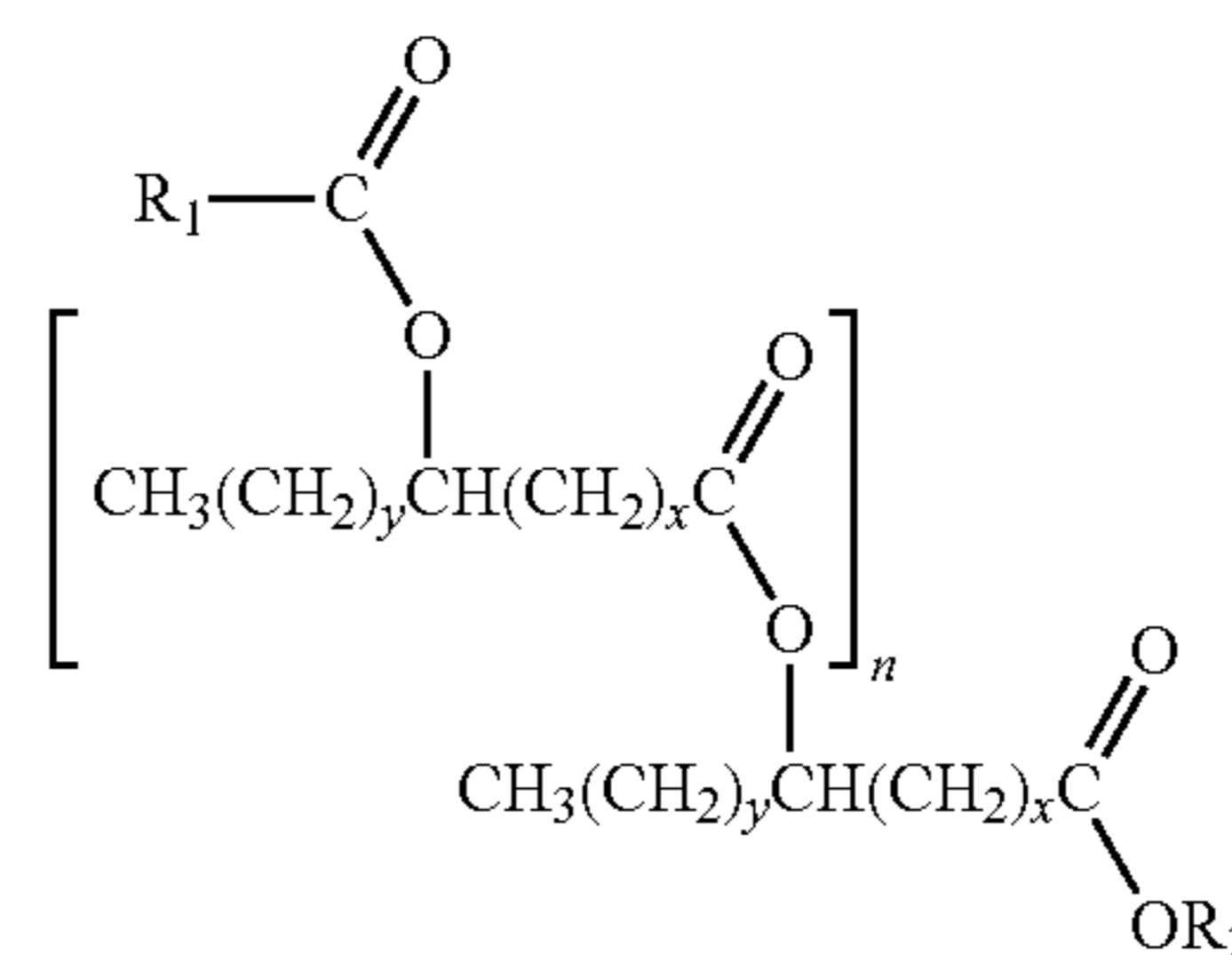
n is an integer equal to or greater than 0;

R<sub>1</sub>, independently for each occurrence, is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched;

R<sub>2</sub> is selected from hydrogen and optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched; and

R<sub>3</sub> and R<sub>4</sub>, independently for each occurrence, are selected from optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched.

In certain embodiments, the estolides comprise at least one estolide compound of Formula III:



Formula III

wherein

x is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20;

y is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20;

n is an integer equal to or greater than 0;

R<sub>1</sub> is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched; and

R<sub>2</sub> is selected from hydrogen and an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched;

wherein each fatty acid chain residue of said at least one compound is independently optionally substituted.

In certain embodiments, the composition comprises at least one estolide of Formula I, II, or III where R<sub>1</sub> is hydrogen.

The terms “chain” or “fatty acid chain” or “fatty acid chain residue,” as used with respect to the estolide compounds of Formula I, II, and III, refer to one or more of the



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fatty acid residues incorporated in estolide compounds, e.g.,  $R_3$  or  $R_4$  of Formula II, or the structures represented by  $CH_3(CH_2)_yCH(CH_2)_xC(O)O-$  in Formula I and III.

The  $R_1$  in Formula I, II, and III at the top of each Formula shown is an example of what may be referred to as a “cap” or “capping material,” as it “caps” the top of the estolide. Similarly, the capping group may be an organic acid residue of general formula  $-OC(O)-alkyl$ , i.e., a carboxylic acid with a substituted or unsubstituted, saturated or unsaturated, and/or branched or unbranched alkyl as defined herein, or a formic acid residue. In certain embodiments, the “cap” or “capping group” is a fatty acid. In certain embodiments, the capping group, regardless of size, is substituted or unsubstituted, saturated or unsaturated, and/or branched or unbranched. The cap or capping material may also be referred to as the primary or alpha ( $\alpha$ ) chain.

Depending on the manner in which the estolide is synthesized, the cap or capping group alkyl may be the only alkyl from an organic acid residue in the resulting estolide that is unsaturated. In certain embodiments, it may be desirable to use a saturated organic or fatty-acid cap to increase the overall saturation of the estolide and/or to increase the resulting estolide’s stability. For example, in certain embodiments, it may be desirable to provide a method of providing a saturated capped estolide by hydrogenating an unsaturated cap using any suitable methods available to those of ordinary skill in the art. Hydrogenation may be used with various sources of the fatty-acid feedstock, which may include mono- and/or polyunsaturated fatty acids. Without being bound to any particular theory, in certain embodiments, hydrogenating the estolide may help to improve the overall stability of the molecule. However, a fully-hydrogenated estolide, such as an estolide with a larger fatty acid cap, may exhibit increased pour point temperatures. In certain embodiments, it may be desirable to offset any loss in desirable pour-point characteristics by using shorter, saturated capping materials.

The  $R_4C(O)O-$  of Formula II or structure  $CH_3(CH_2)_yCH(CH_2)_xC(O)O-$  of Formula I and III serve as the “base” or “base chain residue” of the estolide. Depending on the manner in which the estolide is synthesized, the base organic acid or fatty acid residue may be the only residue that remains in its free-acid form after the initial synthesis of the estolide. However, in certain embodiments, in an effort to alter or improve the properties of the estolide, the free acid may be reacted with any number of substituents. For example, it may be desirable to react the free acid estolide with alcohols, glycols, amines, or other suitable reactants to provide the corresponding ester, amide, or other reaction products. The base or base chain residue may also be referred to as tertiary or gamma ( $\gamma$ ) chains.

The  $R_3C(O)O-$  of Formula II or structure  $CH_3(CH_2)_yCH(CH_2)_xC(O)O-$  of Formula I and III are linking residues that link the capping material and the base fatty-acid residue together. There may be any number of linking residues in the estolide, including when  $n=0$  and the estolide is in its dimer form. Depending on the manner in which the estolide is prepared, a linking residue may be a fatty acid and may initially be in an unsaturated form during synthesis. In some embodiments, the estolide will be formed when a catalyst is used to produce a carbocation at the fatty acid’s site of unsaturation, which is followed by nucleophilic attack on the carbocation by the carboxylic group of another fatty acid. In some embodiments, it may be desirable to have a linking fatty acid that is monounsaturated so that when the

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fatty acids link together, all of the sites of unsaturation are eliminated. The linking residue(s) may also be referred to as secondary or beta ( $\beta$ ) chains.

In certain embodiments, the cap is an acetyl group, the linking residue(s) is one or more fatty acid residues, and the base chain residue is a fatty acid residue. In certain embodiments, the linking residues present in an estolide differ from one another. In certain embodiments, one or more of the linking residues differs from the base chain residue.

As noted above, in certain embodiments, suitable unsaturated fatty acids for preparing the estolides may include any mono- or polyunsaturated fatty acid. For example, mono-unsaturated fatty acids, along with a suitable catalyst, will form a single carbocation that allows for the addition of a second fatty acid, whereby a single link between two fatty acids is formed. Suitable monounsaturated fatty acids may include, but are not limited to, palmitoleic acid (16:1), vaccenic acid (18:1), oleic acid (18:1), eicosenoic acid (20:1), erucic acid (22:1), and nervonic acid (24:1). In addition, in certain embodiments, polyunsaturated fatty acids may be used to create estolides. Suitable polyunsaturated fatty acids may include, but are not limited to, hexadecatrienoic acid (16:3), alpha-linolenic acid (18:3), stearidonic acid (18:4), eicosatrienoic acid (20:3), eicosatetraenoic acid (20:4), eicosapentaenoic acid (20:5), heneicosapentaenoic acid (21:5), docosapentaenoic acid (22:5), docosahexaenoic acid (22:6), tetracosapentaenoic acid (24:5), tetracosahexaenoic acid (24:6), linoleic acid (18:2), gamma-linoleic acid (18:3), eicosadienoic acid (20:2), dihomo-gamma-linolenic acid (20:3), arachidonic acid (20:4), docosadienoic acid (20:2), adrenic acid (22:4), docosapentaenoic acid (22:5), tetracosatetraenoic acid (22:4), tetracosapentaenoic acid (24:5), pinolenic acid (18:3), podocarpic acid (20:3), rumenic acid (18:2), alpha-calendic acid (18:3), beta-calendic acid (18:3), jacaric acid (18:3), alpha-eleostearic acid (18:3), beta-eleostearic (18:3), catalpic acid (18:3), punicic acid (18:3), rumelenic acid (18:3), alpha-parinaric acid (18:4), beta-parinaric acid (18:4), and bosseopentaenoic acid (20:5). In certain embodiments, hydroxy fatty acids may be polymerized or homopolymerized by reacting the carboxylic acid functionality of one fatty acid with the hydroxy functionality of a second fatty acid. Exemplary hydroxyl fatty acids include, but are not limited to, ricinoleic acid, 6-hydroxystearic acid, 9,10-dihydroxystearic acid, 12-hydroxystearic acid, and 14-hydroxystearic acid.

The process for preparing the estolide compounds described herein may include the use of any natural or synthetic fatty acid source. However, it may be desirable to source the fatty acids from a renewable biological feedstock. For example, suitable starting materials of biological origin include, but are not limited to, plant fats, plant oils, plant waxes, animal fats, animal oils, animal waxes, fish fats, fish oils, fish waxes, algal oils and mixtures of two or more thereof. Other potential fatty acid sources include, but are not limited to, waste and recycled food-grade fats and oils, fats, oils, and waxes obtained by genetic engineering, fossil fuel-based materials and other sources of the materials desired.

In certain embodiments, the compounds described herein may be prepared from non-naturally occurring fatty acids derived from naturally occurring feedstocks. In certain embodiments, the compounds are prepared from synthetic fatty acid products derived from naturally occurring feedstocks such as vegetable oils. For example, the synthetic fatty acid product may be prepared by cleaving fragments from larger fatty acid residues occurring in natural oils, such



as triglycerides, using any of the suitable metathesis processes described further below. In certain embodiments, the resulting truncated fatty acid residue(s) may then be liberated from the glycerine backbone using any suitable hydrolytic and/or transesterification processes known to those of skill in the art. An exemplary fatty acid product includes 9-dodecenoic acid, which may be prepared via the cross metathesis of an oleic acid residue with 1-butene. In certain embodiments, the naturally-occurring fatty acid may be liberated from the glycerine backbone prior to being exposed to metathesis. Such metathesis reactions may be non-specific and produce mixtures of products, wherein reactions producing, for example, internally-unsaturated fatty acids such as 9-dodecenoic acid also produce varying amounts of the terminally-unsaturated fatty acid, 9-decenoic acid. In certain embodiments, it may be desirable to optimize the production of fatty acids having at least one terminal site of unsaturation by reacting an unsaturated fatty acid reactant (e.g., oleic acid) with ethylene under metathesis conditions, whereby the terminally-unsaturated fatty acid product (e.g., 9-decenoic acid) is produced exclusively.

In some embodiments, the compound comprises fatty acid chains of varying lengths. In some embodiments,  $x$  is, independently for each occurrence, an integer selected from 0 to 20, 0 to 18, 0 to 16, 0 to 14, 1 to 12, 1 to 10, 2 to 8, 6 to 8, or 4 to 6. In some embodiments,  $x$  is, independently for each occurrence, an integer selected from 7 and 8. In some embodiments,  $x$  is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20. In certain embodiments, for at least one fatty acid chain residue,  $x$  is an integer selected from 7 and 8.

In some embodiments,  $y$  is, independently for each occurrence, an integer selected from 0 to 20, 0 to 18, 0 to 16, 0 to 14, 1 to 12, 1 to 10, 2 to 8, 6 to 8, or 4 to 6. In some embodiments,  $y$  is, independently for each occurrence, an integer selected from 7 and 8. In some embodiments,  $y$  is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20. In certain embodiments, for at least one fatty acid chain residue,  $y$  is an integer selected from 7 and 8. In some embodiments, for at least one fatty acid chain residue,  $y$  is an integer selected from 0 to 6, or 1 and 2. In certain embodiments,  $y$  is, independently for each occurrence, an integer selected from 1 to 6, or 1 and 2.

In some embodiments,  $x+y$  is, independently for each chain, an integer selected from 0 to 40, 0 to 20, 10 to 20, or 12 to 18. In some embodiments,  $x+y$  is, independently for each chain, an integer selected from 13 to 15. In some embodiments,  $x+y$  is 15. In some embodiments,  $x+y$  is, independently for each chain, an integer selected from 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, and 24. In certain embodiments,  $x+y$ , independently for each chain, is an integer selected from 5 to 15. In certain embodiments, for at least one fatty acid chain residue,  $x+y$  is 7. In certain embodiments,  $x+y$  is 7 for each fatty acid chain residue. In certain embodiments, for at least one fatty acid chain residue,  $x+y$  is an integer selected from 9 to 13. In certain embodiments, for at least one fatty acid chain residue,  $x+y$  is 9. In certain embodiments,  $x+y$  is, independently for each chain, an integer selected from 9 to 13. In certain embodiments,  $x+y$  is 9 for each fatty acid chain residue.

In some embodiments, the estolide compound of Formula I, II, or III may comprise any number of fatty acid residues to form an "n-mer" estolide. For example, the estolide may be in its dimer ( $n=0$ ), trimer ( $n=1$ ), tetramer ( $n=2$ ), pentamer

( $n=3$ ), hexamer ( $n=4$ ), heptamer ( $n=5$ ), octamer ( $n=6$ ), nonamer ( $n=7$ ), or decamer ( $n=8$ ) form. In some embodiments,  $n$  is an integer selected from 0 to 20, 0 to 18, 0 to 16, 0 to 14, 0 to 12, 0 to 10, 0 to 8, or 0 to 6. In some embodiments,  $n$  is an integer selected from 0 to 4. In some embodiments,  $n$  is 1, wherein said at least one compound of Formula I, II, or III comprises the trimer. In some embodiments,  $n$  is greater than 1. In some embodiments,  $n$  is an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20.

In some embodiments,  $R_1$  of Formula I, II, or III is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched. In some embodiments, the alkyl group is a  $C_1$  to  $C_{40}$  alkyl,  $C_1$  to  $C_{22}$  alkyl or  $C_1$  to  $C_{18}$  alkyl. In some embodiments, the alkyl group is selected from  $C_7$  to  $C_{17}$  alkyl. In some embodiments,  $R_1$  is selected from  $C_7$  alkyl,  $C_9$  alkyl,  $C_{11}$  alkyl,  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_1$  is selected from  $C_{13}$  to  $C_{17}$  alkyl, such as from  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_1$  is a  $C_1$ ,  $C_2$ ,  $C_3$ ,  $C_4$ ,  $C_5$ ,  $C_6$ ,  $C_7$ ,  $C_8$ ,  $C_9$ ,  $C_{10}$ ,  $C_{11}$ ,  $C_{12}$ ,  $C_{13}$ ,  $C_{14}$ ,  $C_{15}$ ,  $C_{16}$ ,  $C_{17}$ ,  $C_{18}$ ,  $C_{19}$ ,  $C_{20}$ ,  $C_{21}$ , or  $C_{22}$  alkyl.

In some embodiments,  $R_2$  of Formula I, II, or III is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched. In some embodiments, the alkyl group is a  $C_1$  to  $C_{40}$  alkyl,  $C_1$  to  $C_{22}$  alkyl or  $C_1$  to  $C_{18}$  alkyl. In some embodiments, the alkyl group is selected from  $C_7$  to  $C_{17}$  alkyl. In some embodiments,  $R_2$  is selected from  $C_7$  alkyl,  $C_9$  alkyl,  $C_{11}$  alkyl,  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_2$  is selected from  $C_{13}$  to  $C_{17}$  alkyl, such as from  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_2$  is a  $C_1$ ,  $C_2$ ,  $C_3$ ,  $C_4$ ,  $C_5$ ,  $C_6$ ,  $C_7$ ,  $C_8$ ,  $C_9$ ,  $C_{10}$ ,  $C_{11}$ ,  $C_{12}$ ,  $C_{13}$ ,  $C_{14}$ ,  $C_{15}$ ,  $C_{16}$ ,  $C_{17}$ ,  $C_{18}$ ,  $C_{19}$ ,  $C_{20}$ ,  $C_{21}$ , or  $C_{22}$  alkyl.

In some embodiments,  $R_3$  is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched. In some embodiments, the alkyl group is a  $C_1$  to  $C_{40}$  alkyl,  $C_1$  to  $C_{22}$  alkyl or  $C_1$  to  $C_{18}$  alkyl. In some embodiments, the alkyl group is selected from  $C_7$  to  $C_{17}$  alkyl. In some embodiments,  $R_3$  is selected from  $C_7$  alkyl,  $C_9$  alkyl,  $C_{11}$  alkyl,  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_3$  is selected from  $C_{13}$  to  $C_{17}$  alkyl, such as from  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_3$  is a  $C_1$ ,  $C_2$ ,  $C_3$ ,  $C_4$ ,  $C_5$ ,  $C_6$ ,  $C_7$ ,  $C_8$ ,  $C_9$ ,  $C_{10}$ ,  $C_{11}$ ,  $C_{12}$ ,  $C_{13}$ ,  $C_{14}$ ,  $C_{15}$ ,  $C_{16}$ ,  $C_{17}$ ,  $C_{18}$ ,  $C_{19}$ ,  $C_{20}$ ,  $C_{21}$ , or  $C_{22}$  alkyl.

In some embodiments,  $R_4$  is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched. In some embodiments, the alkyl group is a  $C_1$  to  $C_{40}$  alkyl,  $C_1$  to  $C_{22}$  alkyl or  $C_1$  to  $C_{18}$  alkyl. In some embodiments, the alkyl group is selected from  $C_7$  to  $C_{17}$  alkyl. In some embodiments,  $R_4$  is selected from  $C_7$  alkyl,  $C_9$  alkyl,  $C_{11}$  alkyl,  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_4$  is selected from  $C_{13}$  to  $C_{17}$  alkyl, such as from  $C_{13}$  alkyl,  $C_{15}$  alkyl, and  $C_{17}$  alkyl. In some embodiments,  $R_4$  is a  $C_1$ ,  $C_2$ ,  $C_3$ ,  $C_4$ ,  $C_5$ ,  $C_6$ ,  $C_7$ ,  $C_8$ ,  $C_9$ ,  $C_{10}$ ,  $C_{11}$ ,  $C_{12}$ ,  $C_{13}$ ,  $C_{14}$ ,  $C_{15}$ ,  $C_{16}$ ,  $C_{17}$ ,  $C_{18}$ ,  $C_{19}$ ,  $C_{20}$ ,  $C_{21}$ , or  $C_{22}$  alkyl.

As noted above, in certain embodiments, it may be possible to manipulate one or more of the estolides' properties by altering the length of  $R_1$  and/or its degree of saturation. However, in certain embodiments, the level of substitution on  $R_1$  may also be altered to change or even improve the estolides' properties. Without being bound to any particular theory, in certain embodiments, it is believed that the presence of polar substituents on  $R_1$ , such as one or more hydroxy groups, may increase the viscosity of the estolide, while increasing pour point. Accordingly, in some



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embodiments,  $R_1$  will be unsubstituted or optionally substituted with a group that is not hydroxyl.

In some embodiments, the estolide is in its free-acid form, wherein  $R_2$  of Formula I, II, or III is hydrogen. In some embodiments,  $R_2$  is selected from optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched. In certain embodiments, the  $R_2$  residue may comprise any desired alkyl group, such as those derived from esterification of the estolide with the alcohols identified in the examples herein. In some embodiments, the alkyl group is selected from  $C_1$  to  $C_{40}$ ,  $C_1$  to  $C_{22}$ ,  $C_3$  to  $C_{20}$ ,  $C_1$  to  $C_{18}$ , or  $C_6$  to  $C_{12}$  alkyl. In some embodiments,  $R_2$  may be selected from  $C_3$  alkyl,  $C_4$  alkyl,  $C_8$  alkyl,  $C_{12}$  alkyl,  $C_{16}$  alkyl,  $C_{18}$  alkyl, and  $C_{20}$  alkyl. For example, in certain embodiments,  $R_2$  may be branched, such as isopropyl, isobutyl, or 2-ethylhexyl. In some embodiments,  $R_2$  may be a larger alkyl group, branched or unbranched, comprising  $C_{12}$  alkyl,  $C_{16}$  alkyl,  $C_{18}$  alkyl, or  $C_{20}$  alkyl. Such groups at the  $R_2$  position may be derived from esterification of the free-acid estolide using the Jarcol™ line of alcohols marketed by Jarchem Industries, Inc. of Newark, N.J., including Jarcol™ I-18CG, 1-20, 1-12, 1-16, I-18T, and 85BJ. In some cases,  $R_2$  may be sourced from certain alcohols to provide branched alkyls such as isostearyl and isopalmityl. It should be understood that such isopalmityl and isostearyl alkyl groups may cover any branched variation of  $C_{16}$  and  $C_{18}$ , respectively. For example, the estolides described herein may comprise highly-branched isopalmityl or isostearyl groups at the  $R_2$  position, derived from the Fineoxocol® line of isopalmityl and isostearyl alcohols marketed by Nissan Chemical America Corporation of Houston, Tex., including Fineoxocol® 180, 180N, and 1600. Without being bound to any particular theory, in certain embodiments, large, highly-branched alkyl groups (e.g., isopalmityl and isostearyl) at the  $R_2$  position of the estolides can provide at least one way to increase an estolide-containing composition's viscosity, while substantially retaining or even reducing its pour point. In certain embodiments, branched alcohols such as 2-ethylhexanol may provide increased stability to the ester bond of the base residue by making it less susceptible to hydrolysis.

In some embodiments, the compounds described herein may comprise a mixture of two or more estolide compounds of Formula I, II, and III. It is possible to characterize the chemical makeup of an estolide, a mixture of estolides, or a composition comprising estolides, by using the compound's, mixture's, or composition's measured estolide number (EN) of compound or composition. The EN represents the average number of fatty acids added to the base fatty acid. The EN also represents the average number of estolide linkages per molecule:

$$EN=n+1$$

wherein  $n$  is the number of secondary ( $\beta$ ) fatty acids. Accordingly, a single estolide compound will have an EN that is a whole number, for example for dimers, trimers, and tetramers:

- dimer EN=1
- trimer EN=2
- tetramer EN=3

However, a composition comprising two or more estolide compounds may have an EN that is a whole number or a fraction of a whole number. For example, a composition having a 1:1 molar ratio of dimer and trimer would have an EN of 1.5, while a composition having a 1:1 molar ratio of tetramer and trimer would have an EN of 2.5.

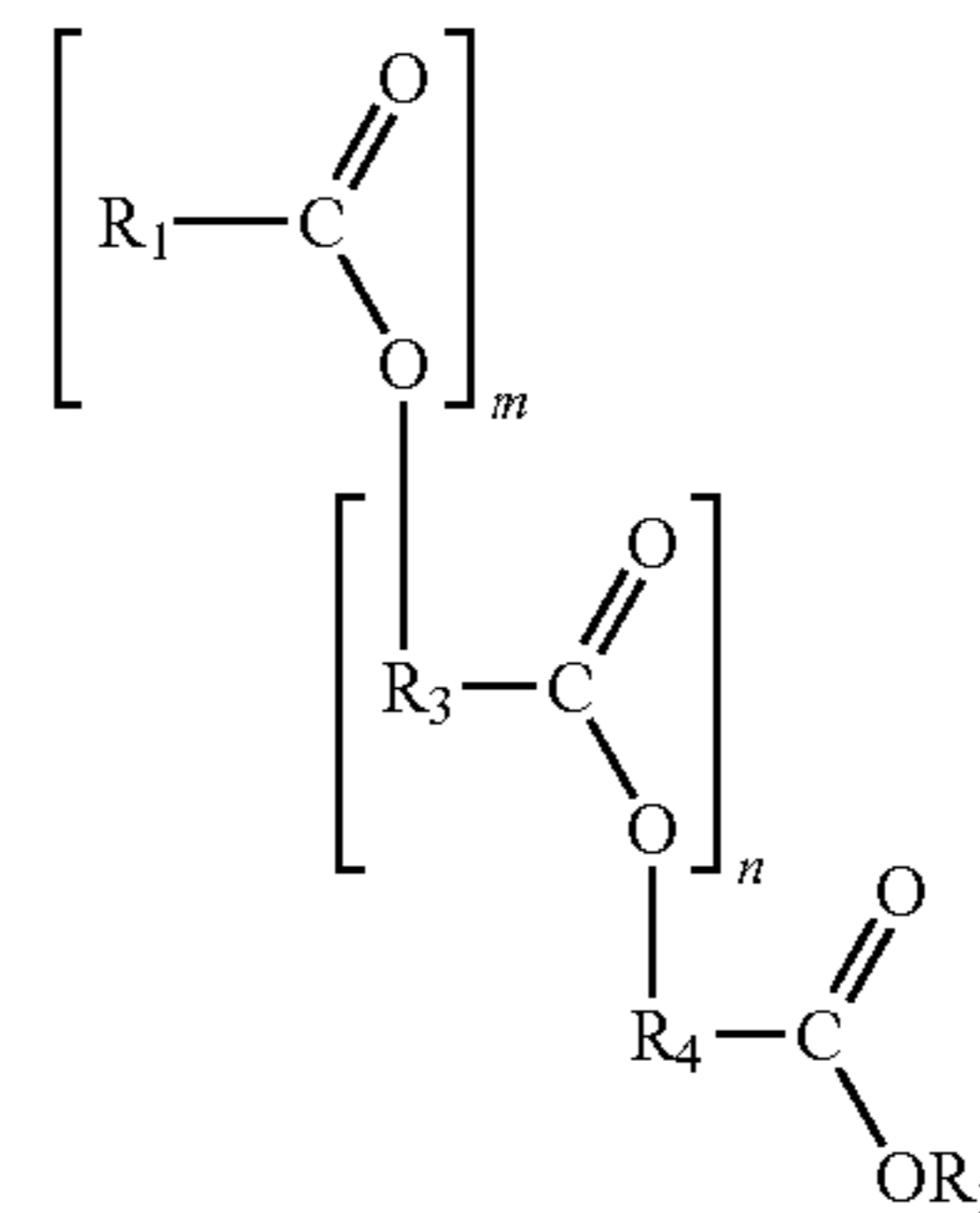
In some embodiments, the compositions may comprise a mixture of two or more estolides having an EN that is an

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integer or fraction of an integer that is greater than 4.5, or even 5.0. In some embodiments, the EN may be an integer or fraction of an integer selected from about 1.0 to about 5.0. In some embodiments, the EN is an integer or fraction of an integer selected from 1.2 to about 4.5. In some embodiments, the EN is selected from a value greater than 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6 and 5.8. In some embodiments, the EN is selected from a value less than 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, and 5.0, 5.2, 5.4, 5.6, 5.8, and 6.0. In some embodiments, the EN is selected from 1, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, and 6.0.

As noted above, it should be understood that the chains of the estolide compounds may be independently optionally substituted, wherein one or more hydrogens are removed and replaced with one or more of the substituents identified herein. Similarly, two or more of the hydrogen residues may be removed to provide one or more sites of unsaturation, such as a cis or trans double bond. Further, the chains may optionally comprise branched hydrocarbon residues. For example, in some embodiments the estolides described herein may comprise at least one compound of Formula II:

Formula II



wherein

$m$  is an integer equal to or greater than 1;

$n$  is an integer equal to or greater than 0;

$R_1$ , independently for each occurrence, is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched;

$R_2$  is selected from hydrogen and optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched; and

$R_3$  and  $R_4$ , independently for each occurrence, are selected from optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched.

In certain embodiments,  $m$  is 1. In some embodiments,  $m$  is an integer selected from 2, 3, 4, and 5. In some embodiments,  $n$  is an integer selected from 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12. In some embodiments, one or more  $R_3$  differs from one or more other  $R_3$  in a compound of Formula II. In some embodiments, one or more  $R_3$  differs from  $R_4$  in a compound of Formula II. In some embodiments, if the compounds of Formula II are prepared from one or more polyunsaturated fatty acids, it is possible that one or more of  $R_3$  and  $R_4$  will have one or more sites of unsaturation. In some embodiments, if the compounds of Formula II are prepared from one or more branched fatty acids, it is possible that one or more of  $R_3$  and  $R_4$  will be branched.

In some embodiments,  $R_3$  and  $R_4$  can be  $CH_3(CH_2)_yCH(CH_2)_x-$ , where  $x$  is, independently for each occurrence, an



integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20, and y is, independently for each occurrence, an integer selected from 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20. Where both  $R_3$  and  $R_4$  are  $\text{CH}_3(\text{CH}_2)_y\text{CH}(\text{CH}_2)_x-$ , the compounds may be compounds according to Formula I and III.

Typically, base stocks and estolide-containing compositions exhibit certain lubricity, viscosity, and/or pour point characteristics. For example, in certain embodiments, the base oils, compounds, and compositions may exhibit viscosities that range from about 10 cSt to about 250 cSt at 40° C., and/or about 3 cSt to about 30 cSt at 100° C. In some embodiments, the base oils, compounds, and compositions may exhibit viscosities within a range from about 50 cSt to about 150 cSt at 40° C., and/or about 10 cSt to about 20 cSt at 100° C.

In some embodiments, the estolide compounds and compositions may exhibit viscosities less than about 55 cSt at 40° C. or less than about 45 cSt at 40° C., and/or less than about 12 cSt at 100° C. or less than about 10 cSt at 100° C. In some embodiments, the estolide compounds and compositions may exhibit viscosities within a range from about 25 cSt to about 55 cSt at 40° C., and/or about 5 cSt to about 11 cSt at 100° C. In some embodiments, the estolide compounds and compositions may exhibit viscosities within a range from about 35 cSt to about 45 cSt at 40° C., and/or about 6 cSt to about 10 cSt at 100° C. In some embodiments, the estolide compounds and compositions may exhibit viscosities within a range from about 38 cSt to about 43 cSt at 40° C., and/or about 7 cSt to about 9 cSt at 100° C.

In some embodiments, estolide compounds and compositions may exhibit desirable low-temperature pour point properties. In some embodiments, the estolide compounds and compositions may exhibit a pour point lower than about -25° C., about -35° C., -40° C., or even about -50° C. In some embodiments, the estolide compounds and compositions have a pour point of about -25° C. to about -45° C. In some embodiments, the pour point falls within a range of about -30° C. to about -40° C., about -34° C. to about -38° C., about -30° C. to about -45° C., -35° C. to about -45° C., 34° C. to about -42° C., about -38° C. to about -42° C., or about 36° C. to about -40° C.

In addition, in certain embodiments, the estolides may exhibit decreased Iodine Values (IV) when compared to estolides prepared by other methods. IV is a measure of the degree of total unsaturation of an oil, and is determined by measuring the amount of iodine per gram of estolide (cg/g). In certain instances, oils having a higher degree of unsaturation may be more susceptible to creating corrosiveness and deposits, and may exhibit lower levels of oxidative stability. Compounds having a higher degree of unsaturation will have more points of unsaturation for iodine to react with, resulting in a higher IV. Thus, in certain embodiments, it may be desirable to reduce the IV of estolides in an effort to increase the oil's oxidative stability, while also decreasing harmful deposits and the corrosiveness of the oil.

In some embodiments, estolide compounds and compositions described herein have an IV of less than about 40 cg/g or less than about 35 cg/g. In some embodiments, estolides have an IV of less than about 30 cg/g, less than about 25 cg/g, less than about 20 cg/g, less than about 15 cg/g, less than about 10 cg/g, or less than about 5 cg/g. The IV of a composition may be reduced by decreasing the estolide's degree of unsaturation. This may be accomplished by, for example, by increasing the amount of saturated capping materials relative to unsaturated capping materials when

synthesizing the estolides. Alternatively, in certain embodiments, IV may be reduced by hydrogenating estolides having unsaturated caps.

In certain embodiments is described a food product containing at least one estolide compound. In certain embodiments, the food product is prepared by a process that includes cooking an article of food in a composition comprising at least one estolide compound. In certain embodiments, the cooking comprises heating the composition to frying temperature, and contacting the article of food with said composition for a time sufficient to fry said article of food. In certain embodiments, the frying temperature is greater than 100° C., such as about 150° C., about 180° C., or about 200° C. In certain embodiments, the frying temperature is less than about 200° C., such as about 190° C. In certain embodiments, the frying temperature is selected from a range of about 100° C. to about 200° C., such as about 150° C. to about 200° C., or about 170° C. to about 190° C.

In certain embodiments, it is believed that estolides may generally serve as a replacement for vegetable oil-based compositions in the food industry. Accordingly, a method of preparing a food product is also described. In certain embodiments, the method comprises cooking an article of food in a composition comprising at least one estolide compound to provide a food product. In certain embodiments, the method comprises including at least one estolide compound in an article of food to provide a food product. In some embodiments, it may be desirable to prepare fry oil compositions comprising an estolide base stock. In certain embodiments, a method of extending the fry life of a cooking oil is described. In certain embodiments, the method comprises contacting at least one cooking oil with a composition comprising at least one estolide compound. For example, in certain embodiments, the estolides described herein may be blended with one or more cooking oils selected from animal-based oils, vegetable oils, polyalphaolefins, synthetic esters, polyalkylene glycols, and mineral oils (Groups I, II, and III). In certain embodiments, the resulting blended cooking oil will exhibit a fry life that is longer when compared to the cooking oil that does not include at least one estolide compound.

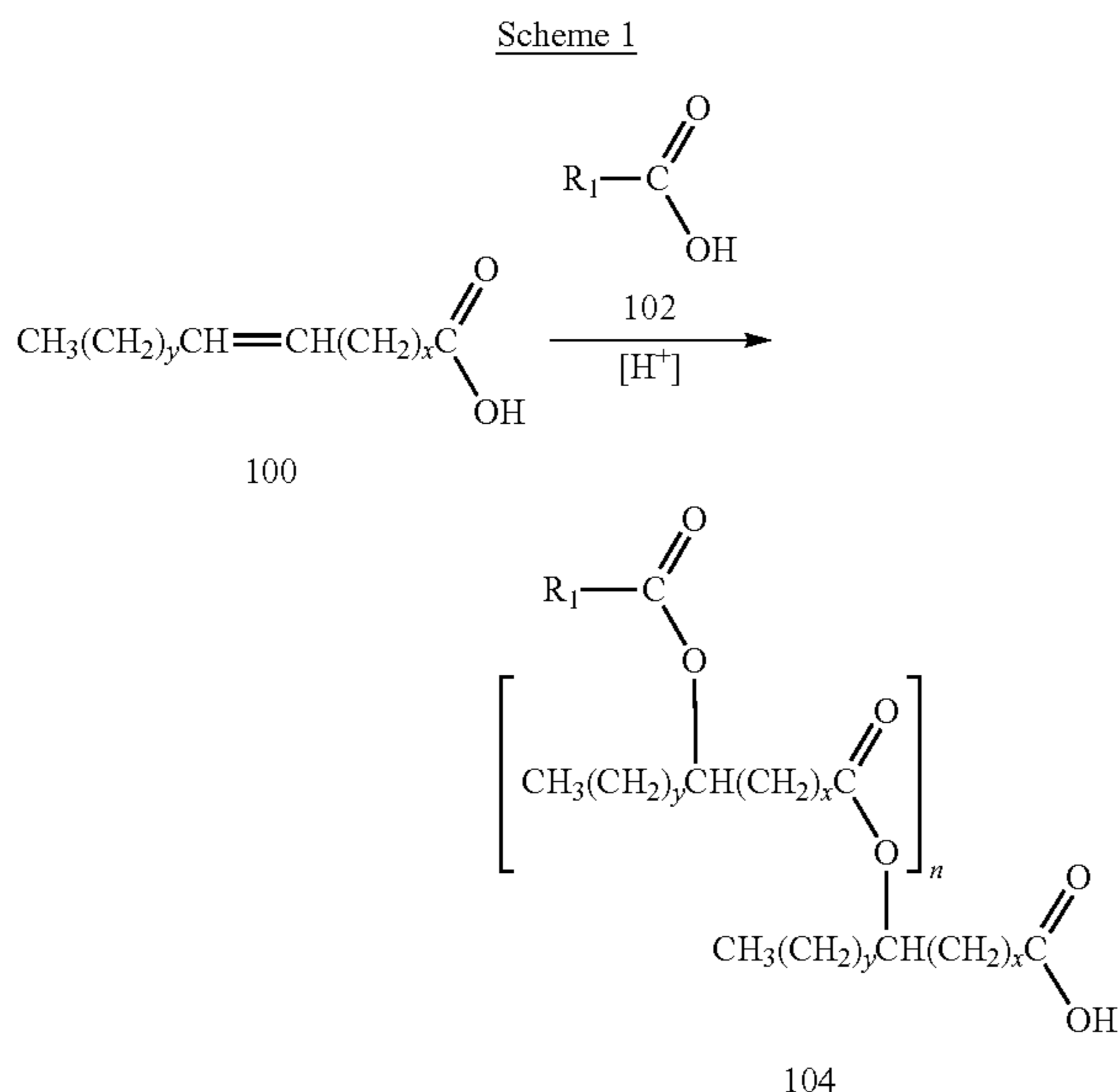
In certain embodiments, the process of producing an estolide base oil comprises oligomerizing one or more free fatty acids in the presence of an oligomerization catalyst, wherein the resulting estolide base oil comprises a free-acid estolide. In certain embodiments, the oligomerization catalyst comprises one or more compounds selected from Bronsted acid catalysts and Lewis acid catalysts, including any known by those of ordinary skill in the art.

The present disclosure further relates to methods of making estolides according to Formula I, II, and III. By way of example, the reaction of an unsaturated fatty acid with an organic acid and the esterification of the resulting free acid estolide are illustrated and discussed in the following Schemes 1 and 2. The particular structural formulas used to illustrate the reactions correspond to those for synthesis of compounds according to Formula I and III; however, the methods apply equally to the synthesis of compounds according to Formula II, with use of compounds having structure corresponding to  $R_3$  and  $R_4$  with a reactive site of unsaturation.

As illustrated below, compound 100 represents an unsaturated fatty acid that may serve as the basis for preparing the estolide compounds described herein.

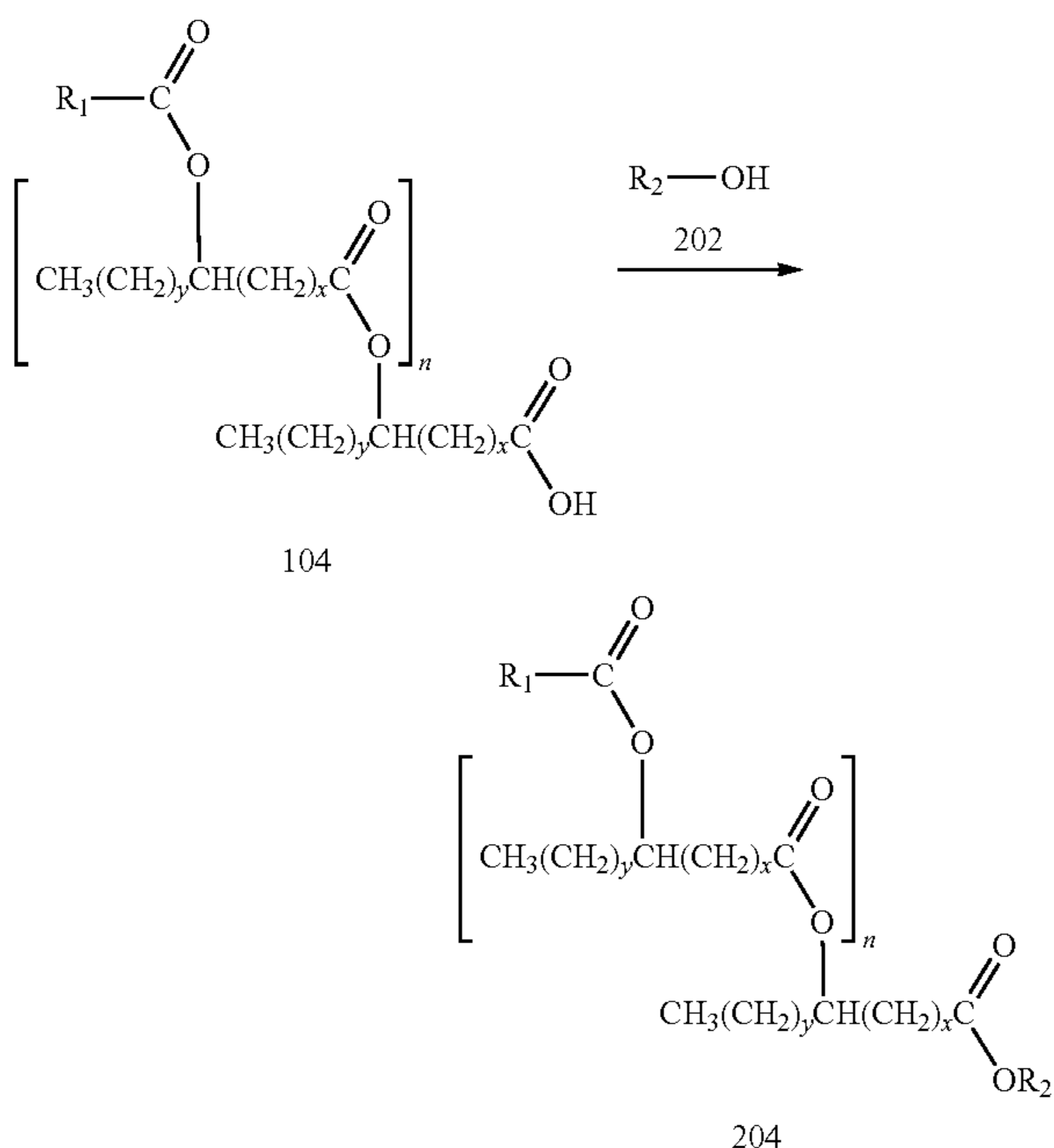


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In Scheme 1, wherein x is, independently for each occurrence, an integer selected from 0 to 20, y is, independently for each occurrence, an integer selected from 0 to 20, n is an integer greater than or equal to 1, and R<sub>1</sub> is an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched, unsaturated fatty acid 100 may be combined with compound 102 and a proton from a proton source to form free acid estolide 104. In certain embodiments, compound 102 is not included, and unsaturated fatty acid 100 may be exposed alone to acidic conditions to form free acid estolide 104, wherein R<sub>1</sub> would represent an unsaturated alkyl group. In certain embodiments, if compound 102 is included in the reaction, R<sub>1</sub> may represent one or more optionally substituted alkyl residues that are saturated or unsaturated and branched or unbranched. Any suitable proton source may be implemented to catalyze the formation of free acid estolide 104, including but not limited to homogenous acids and/or strong acids like hydrochloric acid, sulfuric acid, perchloric acid, nitric acid, triflic acid, and the like.

Scheme 2



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Similarly, in Scheme 2, wherein x is, independently for each occurrence, an integer selected from 0 to 20, y is, independently for each occurrence, an integer selected from 0 to 20, n is an integer greater than or equal to 1, and R<sub>1</sub> and R<sub>2</sub> are each an optionally substituted alkyl that is saturated or unsaturated, and branched or unbranched, free acid estolide 104 may be esterified by any suitable procedure known to those of skilled in the art, such as acid-catalyzed reduction with alcohol 202, to yield esterified estolide 204. Other exemplary methods may include other types of Fischer esterification, such as those using Lewis acid catalysts such as BF<sub>3</sub>.

In all of the foregoing examples, the compounds described may be useful alone, as mixtures, or in combination with other compounds, compositions, and/or materials.

Methods for obtaining the novel compounds described herein will be apparent to those of ordinary skill in the art, suitable procedures being described, for example, in the examples below, and in the references cited herein.

## EXAMPLES

### Analytics

#### Nuclear Magnetic Resonance:

NMR spectra were collected using a Bruker Avance 500 spectrometer with an absolute frequency of 500.113 MHz at 300 K using CDCl<sub>3</sub> as the solvent. Chemical shifts were reported as parts per million from tetramethylsilane. The formation of a secondary ester link between fatty acids, indicating the formation of estolide, was verified with <sup>1</sup>H NMR by a peak at about 4.84 ppm.

#### Estolide Number (EN):

The EN was measured by GC analysis. It should be understood that the EN of a composition specifically refers to EN characteristics of any estolide compounds present in the composition. Accordingly, an estolide composition having a particular EN may also comprise other components, such as natural or synthetic additives, other non-estolide base oils, fatty acid esters, e.g., triglycerides, and/or fatty acids, but the EN as used herein, unless otherwise indicated, refers to the value for the estolide fraction of the estolide composition.

#### Iodine Value (IV):

The iodine value is a measure of the degree of total unsaturation of an oil. IV is expressed in terms of centigrams of iodine absorbed per gram of oil sample. Therefore, the higher the iodine value of an oil the higher the level of unsaturation is of that oil. The IV may be measured and/or estimated by GC analysis. Where a composition includes unsaturated compounds other than estolides as set forth in Formula I, II, and III, the estolides can be separated from other unsaturated compounds present in the composition prior to measuring the iodine value of the constituent estolides. For example, if a composition includes unsaturated fatty acids or triglycerides comprising unsaturated fatty acids, these can be separated from the estolides present in the composition prior to measuring the iodine value for the one or more estolides.

#### Acid Value:

The acid value is a measure of the total acid present in an oil. Acid value may be determined by any suitable titration method known to those of ordinary skill in the art. For example, acid values may be determined by the amount of KOH that is required to neutralize a given sample of oil, and thus may be expressed in terms of mg KOH/g of oil.



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Gas Chromatography (GC):

GC analysis was performed to evaluate the estolide number (EN) and iodine value (IV) of the estolides. This analysis was performed using an Agilent 6890N series gas chromatograph equipped with a flame-ionization detector and an autosampler/injector along with an SP-2380 30 m×0.25 mm i.d. column.

The parameters of the analysis were as follows: column flow at 1.0 mL/min with a helium head pressure of 14.99 psi; split ratio of 50:1; programmed ramp of 120-135° C. at 20° C./min, 135-265° C. at 7° C./min, hold for 5 min at 265° C.; injector and detector temperatures set at 250° C.

Measuring EN and IV by GC:

To perform these analyses, the fatty acid components of an estolide sample were reacted with MeOH to form fatty acid methyl esters by a method that left behind a hydroxy group at sites where estolide links were once present. Standards of fatty acid methyl esters were first analyzed to establish elution times.

Sample Preparation:

To prepare the samples, 10 mg of estolide was combined with 0.5 mL of 0.5M KOH/MeOH in a vial and heated at 100° C. for 1 hour. This was followed by the addition of 1.5 mL of 1.0 M H<sub>2</sub>SO<sub>4</sub>/MeOH and heated at 100° C. for 15 minutes and then allowed to cool to room temperature. One (1) mL of H<sub>2</sub>O and 1 mL of hexane were then added to the vial and the resulting liquid phases were mixed thoroughly. The layers were then allowed to phase separate for 1 minute. The bottom H<sub>2</sub>O layer was removed and discarded. A small amount of drying agent (Na<sub>2</sub>SO<sub>4</sub> anhydrous) was then added to the organic layer after which the organic layer was then transferred to a 2 mL crimp cap vial and analyzed.

EN Calculation:

The EN is measured as the percent hydroxy fatty acids divided by the percent non-hydroxy fatty acids. As an example, a dimer estolide would result in half of the fatty acids containing a hydroxy functional group, with the other half lacking a hydroxyl functional group. Therefore, the EN would be 50% hydroxy fatty acids divided by 50% non-hydroxy fatty acids, resulting in an EN value of 1 that corresponds to the single estolide link between the capping fatty acid and base fatty acid of the dimer.

IV Calculation:

The iodine value is estimated by the following equation based on ASTM Method D97 (ASTM International, Conshohocken, Pa.):

$$IV = \sum 100 \times \frac{A_f \times MW_I \times db}{MW_f}$$

A<sub>f</sub>=fraction of fatty compound in the sample

MW<sub>I</sub>=253.81, atomic weight of two iodine atoms added to a double bond

db=number of double bonds on the fatty compound

MW<sub>f</sub>=molecular weight of the fatty compound

The properties of exemplary estolide compounds and compositions described herein are identified in the following examples and tables.

Other Measurements:

Except as otherwise described, pour point is measured by ASTM Method D97-96a, cloud point is measured by ASTM Method D2500, viscosity/kinematic viscosity is measured by ASTM Method D445-97, viscosity index is measured by ASTM Method D2270-93 (Reapproved 1998), specific gravity is measured by ASTM Method D4052, flash point is

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measured by ASTM Method D92, evaporative loss is measured by ASTM Method D5800, vapor pressure is measured by ASTM Method D5191, and acute aqueous toxicity is measured by Organization of Economic Cooperation and Development (OECD) 203.

## Example 1

The acid catalyst reaction was conducted in a 50 gallon Pfaudler RT-Series glass-lined reactor. Oleic acid (65 Kg, OL 700, Twin Rivers) was added to the reactor with 70% perchloric acid (992.3 mL, Aldrich Cat #244252) and heated to 60° C. in vacuo (10 torr abs) for 24 hrs while continuously being agitated. After 24 hours the vacuum was released. 2-Ethylhexanol (29.97 Kg) was then added to the reactor and the vacuum was restored. The reaction was allowed to continue under the same conditions (60° C., 10 torr abs) for 4 more hours. At which time, KOH (645.58 g) was dissolved in 90% ethanol/water (5000 mL, 90% EtOH by volume) and added to the reactor to quench the acid. The solution was then allowed to cool for approximately 30 minutes. The contents of the reactor were then pumped through a 1 micron (μ) filter into an accumulator to filter out the salts. Water was then added to the accumulator to wash the oil. The two liquid phases were thoroughly mixed together for approximately 1 hour. The solution was then allowed to phase separate for approximately 30 minutes. The water layer was drained and disposed of. The organic layer was again pumped through a 1μ filter back into the reactor. The reactor was heated to 60° C. in vacuo (10 torr abs) until all ethanol and water ceased to distill from solution. The reactor was then heated to 100° C. in vacuo (10 torr abs) and that temperature was maintained until the 2-ethylhexanol ceased to distill from solution. The remaining material was then distilled using a Myers 15 Centrifugal Distillation still at 200° C. under an absolute pressure of approximately 12 microns (0.012 torr) to remove all monoester material leaving behind estolides (Ex. 1). Certain data are reported below in Tables 1 and 6.

## Example 2

The acid catalyst reaction was conducted in a 50 gallon Pfaudler RT-Series glass-lined reactor. Oleic acid (50 Kg, OL 700, Twin Rivers) and whole cut coconut fatty acid (18.754 Kg, TRC 110, Twin Rivers) were added to the reactor with 70% perchloric acid (1145 mL, Aldrich Cat #244252) and heated to 60° C. in vacuo (10 torr abs) for 24 hrs while continuously being agitated. After 24 hours the vacuum was released. 2-Ethylhexanol (34.58 Kg) was then added to the reactor and the vacuum was restored. The reaction was allowed to continue under the same conditions (60° C., 10 torr abs) for 4 more hours. At which time, KOH (744.9 g) was dissolved in 90% ethanol/water (5000 mL, 90% EtOH by volume) and added to the reactor to quench the acid. The solution was then allowed to cool for approximately 30 minutes. The contents of the reactor were then pumped through a 1μ filter into an accumulator to filter out the salts. Water was then added to the accumulator to wash the oil. The two liquid phases were thoroughly mixed together for approximately 1 hour. The solution was then allowed to phase separate for approximately 30 minutes. The water layer was drained and disposed of. The organic layer was again pumped through a 1μ filter back into the reactor. The reactor was heated to 60° C. in vacuo (10 torr abs) until all ethanol and water ceased to distill from solution. The reactor was then heated to 100° C. in vacuo (10 torr abs) and that temperature was maintained until the 2-ethylhexanol



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ceased to distill from solution. The remaining material was then distilled using a Myers 15 Centrifugal Distillation still at 200° C. under an absolute pressure of approximately 12 microns (0.012 torr) to remove all monoester material leaving behind estolides (Ex. 2). Certain data are reported below in Tables 2 and 5.

## Example 3

The estolides produced in Example 1 (Ex. 1) were subjected to distillation conditions in a Myers 15 Centrifugal Distillation still at 300° C. under an absolute pressure of approximately 12 microns (0.012 torr). This resulted in a primary distillate having a lower EN average (Ex. 3A), and a distillation residue having a higher EN average (Ex. 3B). Certain data are reported below in Tables 1 and 6.

TABLE 1

Estolide Base Stock	EN	Pour Point (° C.)	Iodine Value (cg/g)
Ex. 3A	1.35	-32	31.5
Ex. 1	2.34	-40	22.4
Ex. 3B	4.43	-40	13.8

## Example 4

Estolides produced in Example 2 (Ex. 2) were subjected to distillation conditions in a Myers 15 Centrifugal Distillation still at 300° C. under an absolute pressure of approximately 12 microns (0.012 torr). This resulted in a primary distillate having a lower EN average (Ex. 4A), and a distillation residue having a higher EN average (Ex. 4B). Certain data are reported below in Tables 2 and 5.

TABLE 2

Estolide Base Stock	EN	Pour Point (° C.)	Iodine Value (cg/g)
Ex. 4A	1.31	-30	13.8
Ex. 2	1.82	-33	13.2
Ex. 4B	3.22	-36	9.0

## Example 5

Estolides were made according to the method set forth in Example 1, except that the 2-ethylhexanol esterifying alcohol used in Example 1 was replaced with various other alcohols. Alcohols used for esterification include those identified in Table 3 below. The properties of the resulting estolides are set forth in Table 7.

TABLE 3

Alcohol	Structure
Jarcol™ I-18CG	iso-octadecanol
Jarcol™ I-12	2-butyloctanol
Jarcol™ I-20	2-octyldodecanol
Jarcol™ I-16	2-hexyldecanol
Jarcol™ 85BJ	cis-9-octadecen-1-ol
Fineoxocol® 180	iso-stearyl alcohol
Jarcol™ I-18T	2-octyldecanol

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## Example 6

Estolides were made according to the method set forth in Example 2, except the 2-ethylhexanol esterifying alcohol was replaced with isobutanol. The properties of the resulting estolides are set forth in Table 7.

## Example 7

Estolides of Formula I, II, and III are prepared according to the method set forth in Examples 1 and 2, except that the 2-ethylhexanol esterifying alcohol is replaced with various other alcohols. Alcohols to be used for esterification include those identified in Table 4 below. Esterifying alcohols to be used, including those listed below, may be saturated or unsaturated, and branched or unbranched, or substituted with one or more alkyl groups selected from methyl, ethyl, propyl, isopropyl, butyl, isobutyl, sec-butyl, tert-butyl, pentyl, isopentyl, neopentyl, hexyl, isohexyl, and the like, to form a branched or unbranched residue at the R<sub>2</sub> position. Examples of combinations of esterifying alcohols and R<sub>2</sub> substituents are set forth below in Table 4:

TABLE 4

Alcohol	R <sub>2</sub> Substituents
C <sub>1</sub> alkanol	methyl
C <sub>2</sub> alkanol	ethyl
C <sub>3</sub> alkanol	n-propyl, isopropyl
C <sub>4</sub> alkanol	n-butyl, isobutyl, sec-butyl
C <sub>5</sub> alkanol	n-pentyl, isopentyl, neopentyl
C <sub>6</sub> alkanol	n-hexyl, 2-methyl pentyl, 3-methyl pentyl, 2,2-dimethyl butyl, 2,3-dimethyl butyl
C <sub>7</sub> alkanol	n-heptyl and other structural isomers
C <sub>8</sub> alkanol	n-octyl and other structural isomers
C <sub>9</sub> alkanol	n-nonyl and other structural isomers
C <sub>10</sub> alkanol	n-decanyl and other structural isomers
C <sub>11</sub> alkanol	n-undecanyl and other structural isomers
C <sub>12</sub> alkanol	n-dodecanyl and other structural isomers
C <sub>13</sub> alkanol	n-tridecanyl and other structural isomers
C <sub>14</sub> alkanol	n-tetradecanyl and other structural isomers
C <sub>15</sub> alkanol	n-pentadecanyl and other structural isomers
C <sub>16</sub> alkanol	n-hexadecanyl and other structural isomers
C <sub>17</sub> alkanol	n-heptadecanyl and other structural isomers
C <sub>18</sub> alkanol	n-octadecanyl and other structural isomers
C <sub>19</sub> alkanol	n-nonadecanyl and other structural isomers
C <sub>20</sub> alkanol	n-icosanyl and other structural isomers
C <sub>21</sub> alkanol	n-heneicosanyl and other structural isomers
C <sub>22</sub> alkanol	n-docosanyl and other structural isomers

## Example 8

Potato chip preparation: whole peeled potatoes are sliced, washed in water, and fried in the estolide composition prepared according to the method set forth in Example 4A. The Example 4A cooking and frying oil is heated in a pan



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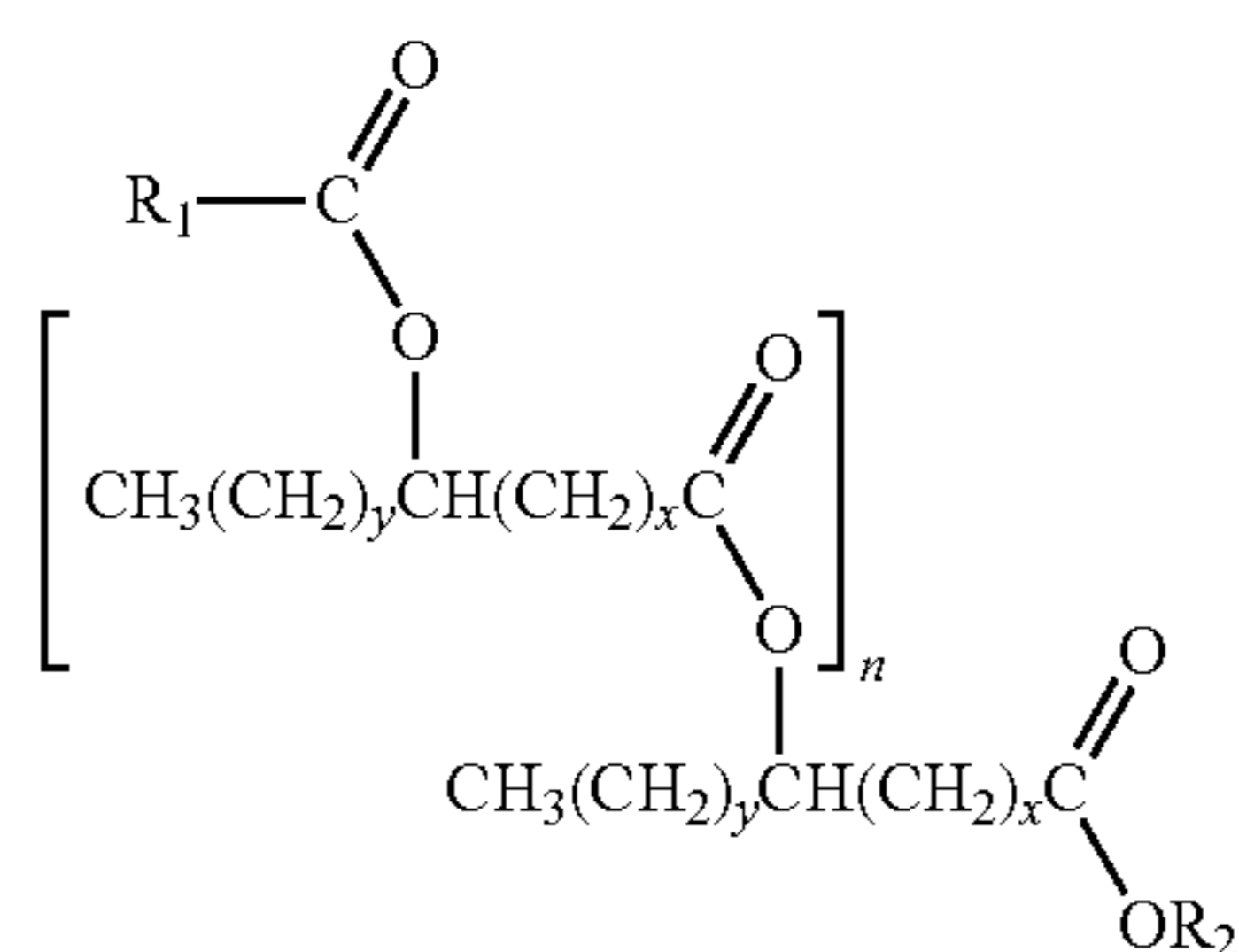
to 375° F., to which the sliced and washed potatoes are added. The potato chips are cooked until a conventional light-brown color is achieved. The excess oil is shaken off the fried potato chips and the chips are then salted to taste.

## Example 9

Cake frosting preparation: vanilla flavor (0.3 wt. %), salt (0.5 wt. %), food colorants (Yellow #5, 0.02 wt. %; Red #40, 0.01 wt. %), microcrystalline cellulose (0.3 wt. %), preservatives (microcrystalline cellulose, 0.3 wt. %; titanium dioxide, 0.27 wt. %; potassium sorbate, 0.10 wt. %; citric acid, 0.02 wt. %) and powdered sugar (57 wt. %) are blended for five minutes using a Hobart paddle mixer at speed one. Ex. 3B estolides (20 wt. %) are added next and blended for five minutes at speed one. In a smaller Hobart paddle mixer, maltodextrin (7.15 wt. %) and polysorbate 80 (0.18 wt. %) are added to water (14.15 wt. %) and blended. This solution or dispersion is then added slowly to the mixing bowl containing the sugar/estolide blend while the paddle mixer is operated at speed one. The water addition takes about one minute and the combined ingredients are scraped down and blended at speed one for one additional minute. After another scrapdown, the entire mixture is whipped for five minutes at speed three.

The invention claimed is:

1. A composition comprising an article of food and at least one estolide compound selected from compounds of Formula I:



Formula I

wherein

x is, independently for each occurrence, an integer selected from 0 to 20;

y is, independently for each occurrence, an integer selected from 0 to 20;

n is an integer greater than or equal to 0;

R<sub>1</sub> is an unsubstituted alkyl that is saturated or unsaturated, and branched or unbranched; and

R<sub>2</sub> is selected from hydrogen and an unsubstituted alkyl that is saturated or unsaturated, and branched or unbranched,

wherein each fatty acid chain residue of said at least one estolide compound is unsubstituted.

2. The composition according to claim 1, wherein

x is, independently for each occurrence, an integer selected from 1 to 10;

y is, independently for each occurrence, an integer selected from 1 to 10;

n is an integer selected from 0 to 8;

R<sub>1</sub> is an unsubstituted C<sub>1</sub> to C<sub>22</sub> alkyl that is saturated or unsaturated, and branched or unbranched; and

R<sub>2</sub> is an unsubstituted C<sub>1</sub> to C<sub>22</sub> alkyl that is saturated or unsaturated, and branched or unbranched, wherein each fatty acid chain residue is unsubstituted.

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3. The composition according to claim 2, wherein x+y is, independently for each chain, an integer selected from 13 to 15; and

n is an integer selected from 0 to 6.

4. The composition according to claim 1, wherein R<sub>2</sub> is a branched or unbranched C<sub>1</sub> to C<sub>20</sub> alkyl that is saturated.

5. The composition according to claim 4, wherein R<sub>2</sub> is selected from C<sub>6</sub> to C<sub>12</sub> alkyl.

6. The composition according to claim 5, wherein R<sub>2</sub> is 2-ethylhexyl.

7. The composition according to claim 1, wherein R<sub>1</sub> is a branched or unbranched C<sub>1</sub> to C<sub>20</sub> alkyl that is saturated or unsaturated.

8. The composition according to claim 7, wherein R<sub>1</sub> is selected from unsubstituted C<sub>7</sub> to C<sub>17</sub> alkyl that is unbranched and saturated or unsaturated.

9. The composition according to claim 8, wherein R<sub>1</sub> is selected from saturated C<sub>7</sub> alkyl, saturated C<sub>9</sub> alkyl, saturated C<sub>11</sub> alkyl, saturated C<sub>13</sub> alkyl, saturated C<sub>15</sub> alkyl, and saturated or unsaturated C<sub>17</sub> alkyl, which are unsubstituted and unbranched.

10. The composition according to claim 1, wherein said composition has an EN selected from an integer or fraction of an integer that is equal to or less than 2, wherein EN is the average number of linkages in compounds according to Formula I, such that the EN for each molecule is determined by EN=n+1, wherein n represents the number of secondary fatty acids.

11. The composition according to claim 10, wherein said composition has a kinematic viscosity equal to or less than 55 cSt when measured at 40° C.

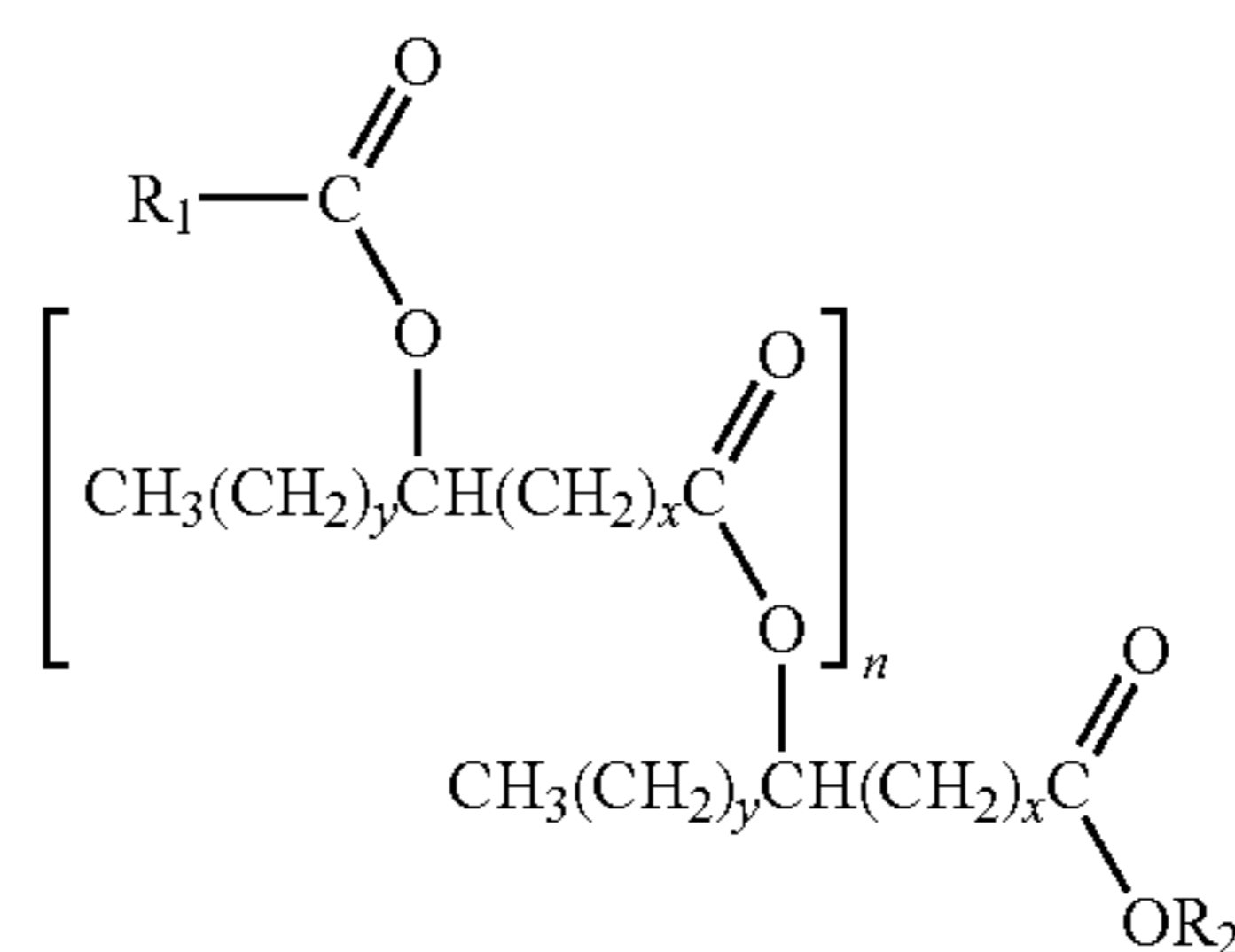
12. The composition according to claim 4, wherein R<sub>2</sub> is ethyl.

13. The composition according to claim 1, wherein x is, independently for each occurrence, an integer selected from 7 and 8.

14. The composition according to claim 13, wherein y is, independently for each occurrence, an integer selected from 7 and 8.

15. The composition according to claim 13, wherein y is 0 for each occurrence.

16. A composition comprising an article of food and at least one estolide compound selected from compounds of Formula I:



Formula I

wherein

x is, independently for each occurrence, an integer selected from 0 to 20;

y is, independently for each occurrence, an integer selected from 0 to 20;

n is an integer greater than or equal to 0;

R<sub>1</sub> is an unsubstituted alkyl that is saturated or unsaturated, and branched or unbranched; and



$R_2$  is an alkyl group substituted with one or more groups selected from —OH and  $OR^{60}$ , wherein  $R^{60}$  is an unsubstituted alkyl or an alkyl substituted with one or more groups selected from —OH and —O-alkyl, wherein each fatty acid chain residue of said at least one estolide compound is unsubstituted.

**17.** The composition according to claim **16**, wherein  $x$  is, independently for each occurrence, an integer selected from 0 to 14;

$y$  is, independently for each occurrence, an integer selected from 0 to 14;

$n$  is an integer selected from 0 to 8;

$R_1$  is an unsubstituted  $C_1$  to  $C_{22}$  alkyl that is saturated or unsaturated, and branched or unbranched; and

$R_2$  is a  $C_1$  to  $C_{22}$  alkyl that is saturated or unsaturated, and branched or unbranched.

**18.** The composition according to claim **17**, wherein  $x+y$  is, independently for each chain, an integer selected from 13 to 15; and

$n$  is an integer selected from 0 to 6.

**19.** The composition according to claim **17**, wherein  $R_2$  is a branched or unbranched  $C_1$  to  $C_{20}$  alkyl that is saturated.

**20.** The composition according to claim **19**, wherein  $R_1$  is an unbranched  $C_1$  to  $C_{20}$  alkyl that is saturated.

**21.** The composition according to claim **19**, wherein  $x$  is, independently for each occurrence, selected from 7 and 8.

**22.** The composition according to claim **21**, wherein  $y$  is, independently for each occurrence, selected from 7 and 8.

**23.** The composition according to claim **21**, wherein  $y$  is 0 for each occurrence.

\* \* \* \* \*